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IDENTIFICATION AND ESTIMATION OF IONS, MOLECULES, AND COMPOUNDS IN PARTICULATE MATTER COLLECTED FROM AMBIENT AIR

FINAL REPORT

Covering the Period
June 30, 1970 to June 30, 1971

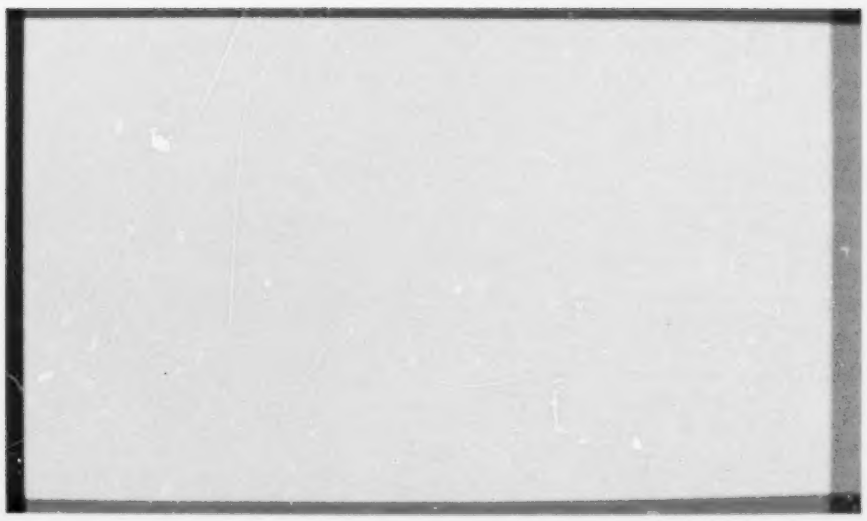
Contract CPA-70-159

Prepared for: Environmental Protection Agency
Air Pollution Control Office

Principal Investigator: W. M. Henry
Author: E. R. Blosser

July 23, 1971

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201



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Battelle
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Telephone (614) 299-3151
Telex 24-5454

July 23, 1971

Dr. Richard J. Thompson
Chief, Air Quality Analytical Laboratory Branch
Division of Atmospheric Surveillance
Environmental Protection Agency
4676 Columbia Parkway
Cincinnati, Ohio 45226

Dear Dr. Thompson:

Ref. Contract CPA 70-159
"Identification and Estimation of Ions, Molecules, and Compounds in Particulate Matter Collected From Ambient Air"

This is the Final Report specified in the above contract covering the period June 30, 1970, through June 30, 1971, distributed according to Mr. DeFord's letter dated January 11, 1971.

When reading the report, please bear in mind that the program was designed as a two-year effort, of which this report covers only the first year. Therefore, much of the work in this report is more or less preliminary to the major effort. A proposed program, with two options, was mailed to you June 29, 1971; this proposal calls for the continuation of the work begun during the present contract.

Very truly yours,

J. F. Foster
for

William M. Henry, Chief
Environmental and Materials Characterization
Division

WMH/JA

cc: Mr. John H. DeFord (1 copy)
EPA, Raleigh (7 copies)

Enclosures (18 plus Original)

MANAGEMENT SUMMARY

Contract CPA 70-159
"Identification and Estimation of Ions, Molecules,
and Compounds in Particulate Matter Collected From Ambient Air"

Objective of Research

This program was designed to characterize the species present in ambient air. The identification of species follows logically the earlier elemental chemical analysis program.

Significance of Research Results to Date

The research reported here has laid the foundation for extensive characterization of air particulates. Data have been generated for elemental composition, including oxygen; for density fractions; for size fractions; and for crystalline components. Most significant is the methodology that has been developed to separate and identify particulate species in air.

Application of Research Results

The data themselves can be used to estimate the proportions of natural and man-made pollutants, and the relative importance of each. The methodology can be applied to additional ambient air samples, to point source samples, or to the samples already on hand. In the latter case, refinements in the techniques should lead to additional, more nearly complete identification of the particulates.

Goals for Next Period

No further work is planned under this contract. A proposed continuation has been sent to Dr. Thompson, EPA.

FOREWORD

The work described in this report was performed under the professional and administrative supervision of Mr. W. M. Henry, with Mr. E. R. Blosser coordinating the various activities. Others of the Battelle staff whose research contributions are gratefully acknowledged include D. L. Chase, W. E. Chase, R. E. Heffelfinger, F. E. Huber, R. B. Iden, D. L. Kiefer, D. F. Kohler, D. K. Landstrom, J. Lathouse, C. T. Litsey, R. L. Livingston, T. L. McKendrick, C. W. Melton, B. Paris, B. F. Phillips, P. M. Schumacher, D. L. Sgontz, B. G. Snyder, R. D. Spaur, M. A. Van Camp, and D. C. Walters.

ABSTRACT

Methods have been developed and applied to ambient air particulate samples to identify and estimate elements and compounds. Preliminary to compound identification, the elemental analyses of some 74 samples collected on filters were obtained using a variety of methods. Oxygen analyses were made using a sample collected on a silver filter; X-ray diffraction studies were performed on samples removed from all-nylon filters, and on density separated fractions of these samples.

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IDENTIFICATION AND ESTIMATION OF IONS, MOLECULES, AND COMPOUNDS IN PARTICULATE MATTER COLLECTED FROM AMBIENT AIR

by

E. R. Blosser

INTRODUCTION

In July, 1969, work began on a project whose ultimate goal was a complete description, qualitatively and quantitatively, of the inorganic components of particulates in ambient urban air. This goal had two facets: a complete elemental analysis; and, insofar as possible, a complete compilation of the individual inorganic species present. The first year's work, presented in the Final Report dated August 14, 1970, was concerned primarily with elemental analyses. About 30 samples on filters were analyzed, most of them by several techniques and for about 77 elements. Initial efforts were made toward the identification of compounds and elemental associations, although this part of the overall task was planned for primary emphasis during the latter phases. The compound identification work did show that the nylon reinforced cellulose ester filters were not well suited for the removal of the sample from the filter. It was, therefore, desirable that a new set of samples be collected for the compound identification work, using filters compatible with the separation steps.

The collection of new samples meant that the elemental analyses should be repeated in order to have a complete set of data - elemental and species - on a given sample. Less emphasis was placed on trace elements, however, because they are quite unlikely to be detected by the structural method, X-ray diffraction (XRD). They would be seen by the microanalysis methods electron microprobe (EMP)

and ion microanalyzer (IMA), in most instances as isolated particles whose abundance would be difficult to relate to the gross sample. For these reasons the primary elemental analytical effort was directed toward the major elements and those elements known or suspected to be unusually toxic. This phase of the planned two-year effort has been completed.

The other aspect of the overall study, the identification of species, was planned for the second phase covering two years. As mentioned earlier, a large part of the effort of this contract period was spent in the preliminary work of the second phase. Simultaneously, intensive work on the separation of the particulates into fractions based on magnetism and density was carried out. As these separations were completed, XRD identification of the crystalline phases in the separated fractions was performed, and experiments leading to the quantification of the XRD data for major components (in work reported here, only α-quartz has been studied) were performed. Finally, one silver filter was analyzed for oxygen using a thermal-mass spectrometric-vacuum fusion approach.

These studies and the results are reported in the Experimental Work section that follows.

EXPERIMENTAL WORK

FILTERS EXAMINED

The filters used in this work, together with the sampling data, are listed in Table 1. The techniques used for each filter are also listed.

ELEMENTAL ANALYSIS

Because the filter material had been changed from that used during the first year's work, and because it is very desirable to have an elemental analysis

TABLE 1. FILTERS EXAMINED

City and Type	Sampling Dates (1970)	Filter No.	Total Particulate Weight, g[a]	Total Air Flow $m^3 \times 10^{-3}$[a,b]	$\mu g/m^3$	Analyses
Cincinnati-Millipore	7/17-7/31	000447(c)	0.777	4.450	175	Not analyzed
	7/31-8/14	000448(c)	0.917	7.819	111	Not analyzed
	8/21-9/4	000451	0.796	5.17	154	Chem., OES, SSMS, XRF, XRD
	9/4-9/18	000452	1.117	8.18	136	Chem., OES, SSMS, XRD
	9/18-10/2	000453	0.982	10.7	92	Chem., OES, SSMS
	10/3-10/17	000454	1.349	11.9	113	Chem., OES
	10/19-11/2	000455	1.224	8.55	143	Chem., OES
	11/2-11/16	000456	1.317	11.6	113	Chem., OES
Cincinnati-Glass	7/17-7/24	009269	1.389	15.241	91	Chem, Hg, SSMS
	7/31-8/7	009270	1.341	15.633	111	Chem., Hg, SSMS
	9/20	009254	0.218	2.7	81	Chem, Hg, SSMS, XRF
	10/3-10/10	009264	1.556	16.4	108	Chem, Hg, SSMS, XRF
	9/18-9/24	009266	1.163	19.4	60	Chem., Hg, SSMS
	9/4-9/11	009267	1.377	16.6	83	Chem., Hg, SSMS, XRF
	8/21-8/28	009268	1.705	14.1	121	Chem., Hg, SSMS, XRF
	11/6-11/23	0010638	1.345	14.9	82	Chem., Hg, XRF,
	11/2-11/9	0010639	1.570	15.2	103	Chem., Hg, XRF
	10/19-10/26	0010640	1.514	14.1	107	Chem., Hg, XRF
Denver-Millipore	7/23-8/6	000445(c)	1.202	9.396	128	Not analyzed
	8/7-8/21	000446(c)	1.195	10.132	118	Not analyzed
	9/4-9/18	000475	1.501	11.6	130	Chem., OES, SSMS, XRF, XRD
	9/18-10/2	000476	1.469	16.5	89	Chem., OES, SSMS
	8/21-9/4	000486	1.444	15.5	93	Chem., OES, SSMS
	10/2-10/16	000477	1.928	10.7	180	Chem., OES
	10/19-11/26	000478	2.058	14.5	142	Chem., OES
	11/2-11/9	000479	3.015	17.3	175	Chem., OES
Denver-Glass	7/23-7/30	0013888	1.966	17.626	112	Chem., Hg, SSMS
	8/7-8/14	0013871	1.995	16.416	122	Chem., Hg, SSMS
	8/21-8/28	009179	1.739	15.0	116	Chem., Hg, SSMS, XRF
	9/4-9/11	0010265	2.142	13.9	154	Chem., Hg, SSMS, XRF
	9/18-9/25	0010290	1.920	17.5	110	Chem., Hg, SSMS, XRF
	10/2-10/9	0010289	2.403	17.0	141	Chem., Hg, XRF
	11/2-11/9	0010291	3.103	16.5	188	Chem., Hg, XRF
	10/19-10/26	0010319	2.146	10.6	202	Chem., Hg, XRF
St. Louis-Millipore	7/9-7/17	000441(c)	0.872	4.262	205	Not analyzed
	7/17-7/31	000442(c)	1.323	7.819	169	Not analyzed
	8/12-8/13	000499	0.141	1.627	87	OES
	9/1-9/3	000500	0.182	2.01	91	Chem., OES, SSMS, XRD
	9/8-9/22	000501	1.558	7.33	213	Chem., OES, SSMS, XRF, XRD
	9/22-10/6	000502	1.202	7.07	170	Chem., OES, SSMS
	10/6-10/19	000503	1.910	11.6	165	Chem., OES
	10/20-10/26	000504	0.921	4.56	202	Chem., OES
	10/27-10/30	000505	0.317	3.03	105	Chem., OES
St. Louis-Glass	7/9-7/16	009066	2.325	17.706	143	Chem., Hg, SSMS
	7/17-7/24	009071	2.107	17.257	122	Chem., Hg, SSMS
	8/12-8/13	009084	2.408	13.406	179	Chem., Hg, SSMS
	8/14-8/18	009084	2.408	13.406	179	Chem., Hg, SSMS
	9/1-9/8	0010142	1.825	16.5	111	Chem., Hg, SSMS, XRF
	9/8-9/15	0010146	2.135	17.1	125	Chem., Hg, SSMS, XRF
	9/22-9/29	0010154	1.833	15.7	117	Chem., Hg, SSMS, XRF
	10/6-10/3	0010161	2.130	18.6	117	Chem., Hg, XRF
	10/20-10/27	0010168	1.722	8.74	197	Chem., Hg, XRF
	10/27-11/3	0010174	1.952	17.7	115	Chem., Hg, XRF
Washington-Millipore	7/14-7/27	000440(c)	0.573	7.358	78	Not analyzed
	8/14-8/25	000511(c)	0.589	2.31	255	Chem., OES, SSMS
	8/28-9/11	000512(c)	0.427	1.79	239	Chem., OES, SSMS
	9/23-10/6	000513(c)	0.886	1.97	450	Chem., OES
	10/12-10/24	000514(c)	0.587	3.66	139	Chem., OES
	10/28-11/12	000515(c)	0.557	4.40	127	Chem., OES
Washington-Glass	7/14-7/20	008978	1.125	16.980	66	Chem., Hg, SSMS
	8/4	009003	0.432	3.80	134	Chem., Hg, SSMS, XRF
	8/14-8/21	009009	1.199	14.6	82	Chem., Hg, SSMS, XRF
	8/22	009012	0.240	2.72	88	Chem., Hg, SSMS, XRF
	8/25	009018	0.278	2.62	106	Chem., Hg, SSMS, XRF
	9/23-9/30	009027	2.517	13.1	192	Chem., Hg, SSMS, XRF
	9/26	009028	0.278	2.80	99	Chem., Hg, XRF
	10/28-11/2	0010114	0.448	9.13	49	Chem., Hg, XRF
	11/4	0010117	0.079	2.13	37	Chem., Hg, XRF
	10/12-10/19	0010134	0.845	12.7	66	Chem., Hg, XRF
Chicago-Millipore	7/22-8/6	000449(c)	1.837	7.775	237	Chem., OES, SSMS
	8/6-8/20	000450(c)	1.267	5.23	242	Chem., OES, SSMS
	9/4-9/18	000463	3.298	8.42	514	Chem., OES, SSMS, XRF, XRD
	10/7-10/20	000464	2.091	7.27	288	Chem., OES
	11/5-11/19	000465	1.954	4.70	416	Chem., OES

TABLE 1. FILTERS EXAMINED (con't)

City and Type	Sampling Dates (1970)	Filter No.	Total Particulate Weight, g[a]	Total Air Flow $m^3 \times 10^{-3}$[a,b]	$\mu g/m^3$	Analyses
Chicago-Glass	7/22-8/3	009273	4.958	12.3	403	Chem., Hg, SSMS, XRF
	8/6-8/14	009275	2.975	12.3	242	Chem., Hg, SSMS, XRF
	9/4-9/11	009278	2.305	6.00	384	Chem., Hg, XRF
	10/7-10/14	009286	2.222	9.59	232	Chem., Hg, XRF
	11/5-11/12	009299	2.067	6.72	308	Chem., Hg, XRF
Philadelphia-Millipore	7/15-7/29	000443(c)	0.954	4.255	224	Not analyzed
	7/29-8/12	000446(c)	0.734	3.732	197	Not analyzed
Philadelphia-Glass	7/15-7/22	009150	2.065	14.262	145	Chem., Hg, SSMS
	7/29-8/5	009125	1.383	9.873	140	Chem., Hg, SSMS
Cincinnati-Silver		NONE	0.959	14.0	68	Chem., OES, SSMS, MS-VF

(a) NAPCA data.
(b) For example, the first entry should be read as 4,450.
(c) Type WSWP cellulose ester - nylon reinforced.

Notes: Chem., = Chemical analysis - usually C, H, N, S, Cl on glass, and F, Na, Mg, K, Ca, Fe, Cu, Zn, Pb on Millipore.
Hg = "Boiler cap" (OES).
OES = Semiquantitative optical emission spectrography.
SSMS = Spark source mass spectrography.
XRF = X-ray fluorescence.
MS-VF = Mass spectrometry-vacuum fusion.
XRD = X-ray diffraction

of the same filter as is subsequently used for specie identification, it was necessary to obtain elemental data, using the new (all-nylon) filters. This work was similar to that of the first year; but with many more data, obtained from collections made over a period of 6 months to a year apart, a better picture of absolute concentrations and city-to-city variations can be obtained. See Tables A-1 and A-2, which are a composite of most of the data.

Conventional Chemical Analysis

The techniques employed for elements present at sufficiently high concentrational levels have been described in the Final Report dated August 14, 1970, of the previous contract (CPA 22-69-153). Briefly, these include atomic absorption analysis of wet-ashed Millipore filter samples, colorimetric analysis for Cl and specific ion electrode analysis for F, and combustion analysis of glass filters for C, H, N, and S. In all cases blanks and synthetic standards were run.

Optical Emission Spectrography

Based upon previous experience, a change was made in this technique from last year. The Millipore filters were ashed directly, with no benzene wash or extraction. The ash was analyzed using the germanium-carbon matrix method as described in the Final Report mentioned above. Mercury was determined using the "boiler cap" technique with glass filter samples that had not been treated in any way.

Spark-Source Mass Spectrography

Again, based on previous experience, the benzene wash step was eliminated; the Millipore filters were ashed directly and the ash was briquetted with graphite and sparked as described in the above-mentioned Final Report. Those elements likely

to be lost during ashing were determined using ground samples of glass filters. It should be noted that the spark source mass spectrograph operates with the samples under a moderate vacuum ($\approx 10^{-6}$ torr); for this reason the Hg results are not believed valid since elemental Hg and many of its compounds are volatile. Therefore, the OES data for Hg should be considered far more reliable since no vacuum is involved; and since only one exposure per sample is made, all the Hg emission is recorded in one "shot", thus precluding the possibility of Hg volatilizing in the first exposure and disappearing in subsequent exposures, as could happen in mass spectrography.

X-Ray Fluorescence

To avoid leaching or ashing steps, the glass filters were chosen for XRF analyses. The very severe disadvantage of high blank values is evident in the tables of glass filter data. Those elements present in the glass occassionally appeared higher or as high in the blank as in the filter plus sample, leading to obviously erroneously low values. The suspected values are marked with an asterisk (*). A portion of the filter pad with its sample was ground in an agate ($SiO_2 \cdot xH_2O$) mortar, briquetted, and analyzed. This treatment was designed to minimize the loss of sensitive elements such as As, Br, and others apt to be lost by heat or extraction.

Oxygen Analysis

One sample of particulate matter collected in Cincinnati on a 20 x 25-cm, 3 μm pore size Selas Flotronics silver filter, was analyzed for oxygen compounds using combined thermal-vacuum fusion-mass spectrometric techniques. The method of analysis was basically that described in the Mid-Point Report of Contract CPA 22-69-153, dated October 13, 1969. A blank silver filter was taken through the same procedure as

the filter with the sample but the amounts of gases released from the blank filter were very small. Water and hydrogen chloride were the major gases released from the blank.

Combination Mass Spectrometry-Vacuum Fusion

A filter sample, about 14.4 cm^2 and containing about a 0.0361 g particulate sample was cut from the 20- x 25-cm filter sheet. This sample was extracted in C_6H_6, with the insoluble sample residue weighing about 0.0355 g. (The sample plus filter weighed 0.4671 g after extraction.) The filter with sample was loaded into a quartz tube and evacuated overnight at room temperature. Following the room temperature evacuation, the temperature of the tube was increased to 100 C for 30 minutes. The gases released are shown in Table 15, and were primarily H_2O. Fluorine, a rather unlikely gas considering the nature of the silver filter, the particulates, and the glass inlet system of the mass spectrometer, was tentatively identified from m/e 19; it seems more probable, however, that m/e 19 is an artifact, possibly H_3O.

These gases were pumped from the system. The temperature was increased to 500 C and held for 30 minutes. During this time the stability of the pressure measurement of the total gases released indicated that 30 minutes was adequate to complete the pyrolysis of the organic oxygen compounds. The results obtained for the 500 C step are shown in Table 15.

The sample container was raised to atmospheric pressure using a blanket of helium and then transferred to the vacuum fusion apparatus. The sample was pumped overnight at room temperature, dropped into the graphite crucible at 1000 C and the temperature was immediately increased to 1700 C. The results obtained for the mass spectrometric analysis of the vacuum fusion run are shown in Table 15.

Direct Vacuum Fusion Extraction

A sample weighing 0.855 g total (0.0650 g extracted sample weight) was loaded directly in the side arm of the vacuum fusion apparatus. It was pumped

overnight at room temperature and run the next day using the procedure described above. The released gases were measured and transferred to the mass spectrometer for analysis. The results obtained are shown in Table 15.

It is of interest to note the total SO_2 from the combination run checked fairly closely with the vacuum fusion run, but only half as much NO appeared in the combination run versus the vacuum fusion extraction.

(Note: The following section, taken from the Mid-Point Report of CPA 22-69-153, is included in this report to demonstrate the validity of the thermal-vacuum fusion-mass spectrometric approach to the oxygen determination.)

Feasibility Study For The Determination of Oxygen

Procedure

Equal parts of the following compounds were mixed to simulate inorganic material that might be present in air-pollution particulate matter: lead bromide, lead oxide, aluminum oxide, silicon dioxide, sodium phosphate, ferric oxide, sodium chloride, and potassium sulfate.

Total Oxygen. A 0.0069-g sample of this material was placed in the vacuum-fusion apparatus and degassed overnight. The material was dropped into the graphite crucible in the furnace at a temperature of 1000 C and the temperature was increased to 1700 C immediately. The gas was extracted for 30 minutes, pumped into an evacuated bulb, and transferred to the mass spectrometer for analysis.

The vacuum fusion-mass spectrometric results showed 0.0023 g of oxygen was liberated from the mix (the theoretical value is 0.0020 g). The recovery of more than 100 percent could be due to absorbed moisture or to water of hydration of some of the compounds in the mix.

Stability of Inorganic Oxygen. Another portion of the sample weighing 0.419 g was placed in a sand-quartz tube and evacuated overnight, and degassed. The material that volatilized at 150, 300, 500, 720, and 900 C was measured and analyzed at each temperature. The sample degassed by resistance heat in the sand-quartz tube at 150 C, showed that some acetone and ethanol had contaminated one or more of the inorganic chemicals used. Seventy percent of the material released at 150 C was water and 26 percent, carbon dioxide. The total oxygen released was 0.00005 g. The total oxygen released for the next two steps (300 and 500 C) was still only 0.0018 g. At 720 C, some of the inorganic material or its impurities decomposed, as 0.0114 g of oxygen was released. At 900 C, very little material was released. Some SO_2 appeared in the gases, indicating some pyrolysis of the K_2SO_4. Total oxygen released at this temperature was only 0.00026 g. The total oxygen released at all the temperatures was 3.2 percent. The heating times were 30 minutes for the 150, 300, and 500 C runs, and 20 minutes for the 720 and 900 C runs.

These experiments indicate that the inorganic materials used in the mixture are stable up to some temperature that is below 720 C and that the vacuum-fusion technique in conjunction with mass spectrometry for analysis can quantitatively measure the oxygen content.

Organic Oxygen. To determine if oxygen could be measured quantitatively if any organic material were mixed with such inorganics, a new sample of the same inorganic mix weighing 0.406 g was added to enough sawdust (0.023 g), screened through No. 40 sieve, to give 5.25 percent organics in the inorganic mix. After evacuation, the sample was degassed at 150 C for 1 hour to remove absorbed gases and water. The composition of the volatilized material was 94 percent water, about 4 percent carbon dioxide, and small amounts of miscellaneous compounds including

the acetone and ethanol observed in the first run. After heating at 500 C for 1 hour the total oxygen in the pyrolysis products was 0.0106 g with 48 percent CO_2, 25 percent H_2O, and 7 percent CO. If we assume that 50 percent of the sawdust (cellulose) is oxygen*, 0.0113 g of oxygen should have been recovered. The results show about 94 percent recovery. The sample was heated to 900 C for 1 hour to see if the presence of carbon (pyrolyzed sawdust) would affect quantitative decomposition of the inorganics at this temperature. Only 33 percent decomposition took place, probably due to insufficient heat, but perhaps also due to insufficient carbon. The vacuum-fusion furnace for the total oxygen determination on the inorganic phase is undoubtedly a more valid approach.

These preliminary results indicate an oxygen analysis on both the organic and inorganic phase of airborne particulate matter might be quantitative using the third method described above to determine organic oxygen, and the vacuum fusion analysis on the residue to determine inorganic oxygen. Obviously, these two results should equal a vacuum fusion result from an original sample. Another duplicate run should be made for verification.

(End of material from earlier report.)

Conclusions

The two experiments with the silver filter, although not conclusive until the results are repeated, demonstrate that the concept of oxygen determination by either the multiple heating or the single vacuum fusion method is valid. It is somewhat disappointing that the material balance did not come closer to 100 percent; on the other hand, the amount of oxygen found is within reason of the amounts to be expected if H_2O, CO_3, SO_4, and oxides are assumed. For example, if all the hydrogen were present as H_2O, the percentage of oxygen required would be 21; if all carbon were CO_3, 72 percent; all sulfur as SO_4, 9 percent; all silicon, calcium, iron, etc. as oxides, about 13 percent. Obviously these assumed forms of oxygen will not be

* Cellulose is approximately $C_xH_{2x}O_x$, and the weight ratio is about $\frac{16}{30} \cong 53$ percent oxygen.

entirely true, especially for carbon, Much of the carbon is known from optical (light) microscopy to be present as "soot" (carbon black, a more or less uncombined form of carbon).

There are several sources of potential error that should be checked if the experiment is repeated. One is the loss of H_2O during the initial evacuation at room temperature. The sample container should be cooled in either Dry Ice-acetone or liquid nitrogen to retain adsorbed H_2O, which would then be included in the 100 C heating step. Other than this possible loss of H_2O, it is believed that the oxygen determination is not the primary souce of error in the material balance summation. The work done in the previous period, summarized above, indicates good oxygen recovery. A second major source of error may be the loss of material, either adsorbed gas or particulate, from the filter between the gross weighing (tare plus sample) and the actual analyses. The amounts of material per m^3 given in all tables are based on EPA sample weights. If these total weights, presumably accurate when made, should change from desorption or mechanical loss during storage, transit, or handling, then obviously the sum of the percentages of elements found but calculated on the as-collected weight, must be low. (Conversely, contamination from dirt or adsorbed gas after collection would make the percentage summation high.) Presumably, the losses would be across-the-board, not any specific element or compound.

Additionally, errors should be sought in the determination of major species, particularly silicon. In this program, Si has been determined by OES, semiquantitatively. A chemical determination would add confidence to the Si value, especially since it is a major element in all samples.

Tabular Data

The results obtained by the 4 elemental techniques - chemical, optical emission, mass spectrography, and X-ray fluorescence - are summarized in Tables 2 through 14. Tables 2 through 6 are analyses of Millipore filters, some of which are

the cellulose ester-nylon reinforced (see Table 1). Tables 7 through 13 are analyses of glass filters. In all these tables (2 through 12) the absence of data for a particular element in the "Chem", "OES", and "XRF" columns means that that element either was not sought or was not detected. In the "SSMS" columns, no data means the element was too high to determine by this technique or was not sought. Table 14 gives the results of the analysis of the one silver filter. For purposes of obtaining the material balance, the data in Table 14 have been converted into weight percent as well as ng/m^3. (Note that the ng/m^3 data in the other tables, 2 through 13, can also be converted easily into weight percentages by dividing by the factor shown for each filter.) Note also that all values are as the element, not as a compound such as oxide.

In those instances where more than one technique gave presumably valid results, and where those results differed appreciably, the value believed most probably correct is underlined. Choice of the best value is subjective, but is based on expected blank error (primarily XRF), inherent lack of precision (primarily SSMS), and other factors. Where there is no known reason to choose one value over another, or where the values did not differ by more than a factor of about 3, no value is underlined.

Note that all data were obtained on the samples as received or as ashed directly. No benzene extractions were made except for the silver filter. Previous work during the preceding year failed to detect any organometallic compounds, and the dried benzene-soluble fraction of extracts were found to contain about the same relative amounts of the same elements as were present in the benzene-insoluble phase; except for Br and I, the absolute quantities were very much lower in the soluble phase.

Other observations made in the Final Report on the first year's work are confirmed in this current effort. High Si is present in all cities; Pb is quite high; V is found at much higher concentrations in some cities than in others, probably as a result of the source of fuel oil. Mercury, an element of intense interest, is definitely present in Denver, Chicago, and Philadelphia, but not unambiguously present in the other 3 cities.

TABLE 2. ANALYSIS OF AIR PARTICULATES ON MILLIPORE - CINCINNATI
(Nanograms/m³)

	Sample Designation													
	000651				000652			000653			000654	000655	000656
Element	Chem.[a]	OES[a]	SSMS[a]	XRF[a]	Chem.	OES	SSMS	Chem.	OES	SSMS	OES	OES	OES
Li			3.0				1.0			3.0			
Be		<4.0(T)[b]	0.1			<4.0(T)	0.1		<2.0(T)	0.1	<3.0(T)	<4.0(T)	<3.0(T)
B		20.0	10.0			20.0	6.0		10.0	6.0	15.0	12.0	20.0
F	<1,000.0		10.0		<1,000		4.0			10.0			
Na	300.0	400.0			600.0	400.0			900.0		400.0	400.0	400.0
Mg	2,100.0	1,450.0			1,800.0	1,800.0			930.0		1,900.0	2,000.0	1,500.0
Al		4,000.0		6,600.0		4,300.0			2,100.0			2,000.0	4,000.0
Si		7,700.0		13,000		8,600.0			4,200.0		6,300.0	7,000.0	7,700.0
P			30.0	240.0			20.0			15.0			
S			600.0	5,560.0			600.0			500.0			
Cl			10.0	<30.0			20.0			15.0	6,300(c)	5,800(c)	7,000(c)
K	1,400.0	2,400.0		1,740.0	1,200.0	2,400.0			1,400.0		1,300.0	1,400.0	1,500.0
Ca	7,200.0	7,700.0		8,600.0	6,100.0	8,500.0			4,200.0		4,200.0	4,400.0	400.0
Sc			2.0				1.0			1.0			
Ti		200.0		<10.0		240.0			140.0		200.0	300.0	400.0
V		10.0	10.0			6.0	6.0		3.0	3.0	13.0	12.0	22.0
Cr		40.0	30.0	45.0		40.0	20.0		20.0	20.0	20.0	20.0	20.0
Mn		300.0		550.0		430.0			230.0		500.0	400.0	200.0
Fe	7,600.0	3,900.0		8,800.0	11,100.0	4,300.0			2,100.0		3,300.0	3,000.0	3,200.0
Co		7.0	0.5	10.0		4.0	1.0		2.0	0.5	3.0	4.0	4.0
Ni		20.0	20.0	30.0		18.0	20.0		14.0	20.0	13.0	12.0	15.0
Cu	3,900.0	2,400.0	2,500.0	8,300.0	1,300.0	240.0	260.0		140.0	100.0	250.0	400.0	400.0
Zn	2,600.0	1,400.0	1,000.0	1,930.0	4,100.0	2,500.0	2,000.0			1,500.0	3,200.0	2,800.0	2,200.0
Ga			0.4	<20			0.2			0.5			
Ge			1.0				0.5			0.5			
As			3.0	<30			0.5			0.5			
Se			3.0	<20			1.0			1.0			
Br			10.0	<20.0			10.0			10.0			
Rb			10.0				10.0			10.0			
Sr			1.0				10.0			10.0			
Y			0.6				2.0			2.0			
Zr		10.0	10.0			20.0	10.0		10.0	10.0	15.0	12.0	20.0
Nb			0.3				0.6			0.5			
Mo		4.0	2.0			4.0	4.0		2.0	2.0	1.0	4.0	4.0
Ru			<0.03				<0.02			<0.02			
Rh			<0.02				<0.06			<0.05			
Pd			<0.3				<0.2			<0.2			
Ag		4.0	0.5			4.0	0.1		2.0	0.1	1.0	4.0	4.0
Cd			10.0				3.0			2.0			
In			<0.1				<0.1			<0.1			
Sn		40.0	20.0	70.0		6.0	20.0		30.0	30.0	90.0	40.0	200.0
Sb			3.0				1.0			1.0			
Te			<0.2	<20.0			<0.2			<0.2			
I			<0.02				<0.02			<0.02			
Cs			0.3				0.1			0.1			
Ba		40.0	30.0	70.0		40.0	60.0		15.0	40.0	20.0	40.0	40.0
La			5.0				3.0			3.0			
Ce			10.0				6.0			5.0			
Pr			2.0				2.0			2.0			
Nd			3.0				4.0			3.0			
Sm			1.0				1.0			1.0			
Eu			0.1				0.1			0.1			
Gd			0.5				0.3			0.3			
Tb			0.05				0.05			0.05			
Dy			0.3				0.2			0.2			
Ho			0.05				0.04			0.04			
Er			0.1				0.05			0.05			
Tm			0.02				0.02			0.02			
Yb			0.1				0.06			0.06			
Lu			0.02				0.02			0.02			
Hf			0.03				0.1			0.1			
Ta			<2.0				<2.0			<2.0			
W			0.1				0.1			0.1			
Re			<0.003				<0.003			<0.003			
Os			<0.006				<0.006			<0.005			
Ir			<0.003				<0.004			<0.003			
Pt			<0.01				<0.01			<0.01			
Au			<0.01				<0.01			<0.01			
Hg		2.0	<0.01			0.6	<0.01		2.1	<0.01	<0.4	<0.6	<0.4
Tl			0.05				0.06			0.05			
Pb	4,000.0	2,400.0	2,000.0	2,600.0	5,800.0	3,700.0	3,800.0	3,300.0	1,900.0	2,000.0	650.0	2,000.0	2,200.0
Bi			0.3				0.4			0.5			
Th			0.2				0.4			0.2			
U			0.1				0.4			0.2			
w/o factor (d)		1,540.0				1,360.0			920.0		1,150.0	1,430.0	1,130.0

(a) Chem. = Wet chemical (primarily atomic absorption).
(a) OES = Optical emission spectrographic.
(a) SSMS = Spark source mass spectrographic.
(a) XRF = X-ray fluorescence.
(b) T = Trace.
(c) Cl by Wet Chemical.
(d) Divide tabulated (ng/m³) value by factor to obtain weight percent
____ Preferred value underlined.

TABLE 3. ANALYSIS OF AIR PARTICULATES ON MILLIPORE - DENVER
(Nanograms/m³)

Element	Sample Designation													
	000475				000476			000496			000477	000478	000479	
	Chem.(a)	OES(a)	SSMS(a)	XRF(a)	Chem.	OES	SSMS	Chem.	OES	SSMS	OES	OES	OES	
Li			10.0				6.0			6.0				
Be		<1.0	0.2			<1.	0.1		<1.0	0.1	<1.0	<1.0	<1.0	
B		15.0	15.0			10.0	10.0		10.0	10.0	20.0	20.0	20.0	
F	1,000.0		50.0		1,000.0		20.0	1,000.0		20.0				
Na	200.0	1,750.0			200.0	1,200.0		300.0	300.0		2,000.0	1,000.0	2,300.0	
Mg	1,300.0	900.0			700.0	600.0		800.0	700.0		500.0	500.0	1,200.0	
Al		4,300.0		11,400.0		3,000.0			3,200.0		6,500.0	7,000.0	6,200.0	
Si		17,000.0		32,100.0		12,000.0			13,000.0		19,000.0	19,000.0	12,000.0	
P			100.0	210.0			60.0			60.0				
S			1,500.0	<50.0			1,000.0			1,000.0				
Cl			100.0	<50.0			60.0			60.0	8,000(b)	3,700(b)	3,900(b)	
K	1,100.0	4,000.0		4,100	400.0	2,000.0		400.0	2,000.0		2,000.0	2,000.0	3,800.0	
Ca	3,800.0	3,000.0		5,300.0	2,400.0	2,000.0		2,900.0	2,000.0		2,900.0	2,900.0	3,800.0	
Sc			3.0				2.0			2.0				
Ti		300.0		130.0		200.0			100.0		500.0	500.0	400.0	
V		4.0	10.0			3.0	6.0		3.0	6.0	10.0	3.0	10.0	
Cr		10.0	20.0	<10.0		3.0	10.0	5.0		10.0	10.0	10.0	10.0	
Mn		40.0		125.0		30.0			30.0		50.0	40.0	30.0	
Fe	7,900.0	3,400.0		7,000.0	3,700.0	1,800.0		4,400.0	2,000.0		2,800.0	2,800.0	3,800.0	
Co		4.0	1.0	<10.0		3.0	0.6		3.0	0.6	3.0	3.0	6.0	
Ni		10.0	10.0	30.0		6.0	6.0		6.0	6.0	10.0	10.0	12.0	
Cu	1,100.0	900.0	300.0	1,700.0	300.0	200.0	300.0	1,100.0	700.0	300.0	700.0	400.0	500.0	
Zn	400.0	300.0	300.0	300.0	300.0	200.0	200.0	300.0	100.0	200.0	200.0	200.0	100.0	
Ge			1.0	<30.0			0.6			0.6				
Ga			<3.0				<2.0			<2.0				
As			3.0	350.0			2.0			2.0				
Se			<3.0	<30.0			<2.0			<2.0				
Br			30.0	300.0			20.0			20.0				
Rb			3.0				3.0			3.0				
Sr			5.0				3.0			3.0				
Y			3.0				3.0			3.0				
Zr			15.0				10.0			10.0	30.0	30.0	20.0	
Nb			1.0				0.6			0.6				
Mo		20.0	30.0			30.0	20.0		10.0	20.0	10.0	3.0	10.0	
Ru			<0.1			<0.06			<0.06					
Rh			<0.05				<0.1			<0.1				
Pd			<1.0				<0.6			<0.6				
Ag		4.0	0.1			3.0	0.1		3.0	0.1	3.0	3.0	6.0	
Cd			3.0				3.0			3.0				
In			<0.5			<0.1			<0.1					
Sn		10.0	7.0	<10.0		6.0	4.0		4.0	4.0	10.0	10.0	10.0	
Sb			2.0			1.0			1.0					
Te			<0.1	<20.0			<0.06			<0.06				
I			0.1				0.06			0.06				
Cs			1.0				0.6			0.6				
Ba		90.0	100.0	130.0		60.0	60.0		30.0	60.0	200.0	100.0	100.0	
La			3.0				3.0			3.0				
Ce			20.0				10.0			10.0				
Pr			2.0				1.0			1.0				
Nd			10.0				6.0			6.0				
Sm			1.0				0.6			0.6				
Eu			0.3				0.3			0.3				
Gd			0.3				0.3			0.3				
Tb			0.1				0.06			0.06				
Dy			0.5				0.3			0.3				
Ho			0.1				0.06			0.06				
Er			0.3				0..			0.1				
Tm			0.01				0.006			0.006				
Yb			0.3				0.2			0.2				
Lu			0.01				0.02			0.02				
Hf			0.3				0.2			0.2				
Ta			<10.0				<20.0			<6.0				
W			0.3				0.6			0.6				
Re			0.5				0.4			0.4				
Os			<0.03				<0.02			<0.02				
Ir			<0.02				<0.01			<0.01				
Pt			<0.05				<0.03			<0.03				
Au			<0.05				<0.03			<0.03				
Hg		2.0	<0.05			1.0	<0.1		1.0	<0.1	2.0	1.0	0.5	
Tl			0.1				0.06			0.06				
Pb	3,700.0	2,400.0	2,500.0	3,400.0	3,300.0	2,000.0	1,500.0	2,900.0	3,200.0	1,500.0	2,800.0	2,800.0	2,300.0	
Bi			1.0				0.6			2.0				
Th			1.0				0.6			2.0				
U			0.3				0.2			1.0				
u/m factor (c)	1,500.0				890.0			930.0			1,800.0	1,400.0	1,750.0	

(a) Chem. = wet chemical (primarily atomic absorption).
(a) OES = Optical emission spectrographic.
(a) SSMS = Spark source mass spectrographic.
(a) XRF = X-ray fluorescence.
(b) Cl by wet chemical.
(c) Divide tabulated (ng/m³) value by factor to obtain weight percent.
_____ Preferred value underlined.

TABLE 4. ANALYSIS OF AIR PARTICULATES ON MILLIPORE - ST. LOUIS
(Nanograms/m^3)

	Sample Designation													
	000499	000500			000501				000502			000503	000504	000505
Element	OES	Chem.(a)	OES(a)	SSMS(a)	Chem.	OES	SSMS	XRF	Chem.	OES	SSMS	OES	OES	OES
Li				6.			1.				6.			
Be			◁2.	0.1		◁1.	0.3			◁1.	0.005	◁13.(T)(b)	◁1.(T)	◁1.
B	15.		10.	10.		30.	20.			3.	5.	20.	4.	10.
F		◁1,000.		30.	◁1,000.		150.		1,800.		150.			
Na	150.	<100.	150.		1,200.	700.			900.	700.		5,000.	3,000.	100.
Mg	600.	1,600.	500.		2,700.	3,000.			2,700.	5,000.		3,000.	1,700.	2,000.
Al	1,000.		1,500.			7,500.		10,200.		7,000.		5,000.	3,000.	2,000.
Si	3,000.		5,000.			31,000.		32,600.		26,000.		10,000.	9,000.	7,000.
P				60.			300.	1,150.			100.			
S				1,000.			6,000.	15,800.			600.			
Cl				150.			600.	2,450.			200.	5,600.	11,900.	9,600.
K		500.	200.		1,400.	1,400.		3,800.	1,000.	1,400.		900.	700.	300.
Ca	3,000.	7,000.	4,000.		19,600.	30,000.		31,000.	19,300.	14,000.		10,000.	9,000.	7,000.
Sc				2.			3.				0.8			
Ti	150.		50.			300.		240.		300.		300.	300.	300.
V	90.		2.	6.		10.	20.			10.	20.	4.	10.	7.
Cr	30.		10.	30.		60.	60.	◁10.		3.	6.	20.	20.	10.
Mn	60.		20.			10.		◁20.	6,600.	100.		90.	90.	70.
Fe	1,500.	3,000.	1,000.		9,400.	6,100.		13,000	6,600.	5,000.		5,000.	3,000.	3,000.
Co	3.		2.	1.		7.	2.	◁10.		2.	0.3	4.	4.	3.
Ni	60.		10.	10.		30.	30.	5.		1.	2.	20.	20.	10.
Cu	150.	800.	500.	300.	2,400.	1,400.	2,200.	2,850.	3,200.	3,000.	2,000.	600.	3,000.	2,000.
Zn	100.	800.	200.	300.	3,500.	3,000.	2,000.	2,850.	1,600.	700.	1,000.	500.	3,000.	200.
Ga				0.6			2.	◁20.			0.2			
Ge				3.			10.				1.			
As				3.			10.	◁50.			6.			
Se				10.			10.	◁20.			◁2.			
Br				60.			60.	◁20.			40.			
Rb				3.			100.				30.			
Sr				3.			30.				30.			
Y				1.			6.				1.			
Zr	15.		5.	4.		40.	40.			1.	3.	20.	10.	10.
Nb				1.			6.				1.			
Mo			◁2.(T)	60.		7.	10.			7.	6.	4.	4.	3.
Ru				◁0.2			◁0.6				◁0.2			
Rh				◁0.06			◁0.1				◁0.1			
Pd				◁0.06			◁1.				◁0.6			
Ag			2.	0.6		7.	2.			7.	0.6	4.	4.	3.
Cd				6.			10.				1.			
In				◁0.6			◁1.				◁0.4			
Sn	3.		15.	40.		15.	100.	15.		7.	10.	40.	200.	30.
Sb				3.			6.				2.			
Te				0.1			◁2.	24.			◁0.6			
I				0.24			◁0.1				◁0.04			
Cs				0.6			3.				1.0			
Ba	15.		15.	300.		70.	300.	150.		4.	30.	90.	90.	100.
La				1.			10.				4.			
Ce				6.			20.				6.			
Pr				0.6			10.				3.			
Nd				6.			10.				3.			
Sm				0.6			6.				0.6			
Eu				0.2			◁1.				0.4			
Gd				0.2			2.				0.4			
Tb				0.06			◁0.6				◁0.2			
Dy				0.3			2.				0.2			
Ho				0.06			◁0.2				◁0.06			
Er				0.06			◁0.2				◁0.06			
Tm				◁0.02			0.2				◁0.03			
Yb				◁0.2			2.				0.2			
Lu				◁0.06			◁0.2				0.06			
Hf				0.06			0.6				0.1			
Ta				◁5.			◁5.				◁20.			
W				0.1			0.6				0.2			
Re				◁0.03			◁0.1				◁0.06			
Os				◁0.02			◁0.06				◁0.04			
Ir				◁0.01			◁0.03				◁0.02			
Pt				◁0.03			◁0.06				◁0.04			
Au				◁0.03			◁0.06				◁0.04			
Hg		◁.	◁.	◁0.06		9.7	◁0.06			9.7	◁0.06	0.4	1.	2.
Tl				0.03			0.06				0.06			
Pb		200.	3,000.	1,500.	1,000.	7,900.	5,000.	4,000.	3,000	6,200.	5,500.	4,000.	860.	1,700.	1,300.
Bi				0.06			6.				0.6			
Th				0.06			0.6				0.2			
U				0.3			2.				0.8			
w/o factor(d)		870.		910.		2,130.				1,700.		1,650.	2,020.	1,050.

(a) Chem. = Wet chemical (primarily atomic absorption).
(a) OES = Optical emission spectrographic.
(a) SSMS = Spark source mass spectrographic
(a) XRF = X-ray fluorescence.
(b) T = Trace
(c) Cl by wet chemical
(d) Divide tabulated (ng/m^3) value by factor to obtain weight percent.
Preferred value underlined.

TABLE 5. ANALYSIS OF AIR PARTICULATES ON MILLIPORE - WASHINGTON
(Nanograms/m³)

	Sample Designation								
	000511			000512			000513	000514	000515
Element	Chem.[a]	OES[a]	SSMS[a]	Chem.	OES	SSMS	OES	OES	OES
Li			6.			6.			
Be		<7.(T)[b]	0.2		<5.(T)	0.2	<10.(T)	<4.(T)	<3.(T)
B		10.	6.		8.	6.	20.	7.	6.
F	<1,000.		10.	<1,000.		10.			
Na	700.	1,000.		800.	600.		800.	1,000.	1,000.
Mg	2,600.	2,000.		2,200.	1,000.		5,000.	2,000.	2,000.
Al		5,000.			4,000.		13,000.	3,000.	3,000.
Si		20,000.			20,000.		25,000.	7,000.	6,000.
P			1,000.			1,000.			
S			1,000.			1,000.			
Cl			10.			10.			
K	1,100.	3,000.		1,400.	3,000.		3,000.	1,000.	1,000.
Ca	6,300.	3,000.		5,000.	3,000.		8,000.	3,000.	3,000.
Sc			2.			2.			
Ti		700.			600.		1,000.	400.	300.
V		100.	200.		60.	60.	200.	100.	200.
Cr		40.	40.		30.	40.	50.	10.	20.
Mn		100.			60.		200.	70.	60.
Fe	8,000.	4,000.		6,700.	4,000.		13,000.	2,000.	3,000.
Co		7.	4.		6.	4.	10.	4.	3.
Ni		70.	40.		30.	40.	10.	80.	40.
Cu	800.	800.	400.	2,100.	1,000.	2,000.	1,000.	1,000.	1,000.
Zn	1,000.	700.	400.	1,100.	200.	100.	200.	300.	300.
Ga			0.6			2.			
Ge			<0.2			<0.2			
As			4.0			2.0			
Se			<1.			<1.			
Br			2.			0.6			
Rb			20.			20.			
Sr			20.			20.			
Y			4.			4.			
Zr		10.	6.		8.	6.	50.	10.	10.
Nb			4.			4.			
Mo		7.	4.		<5.	4.	<10.(T)	<4.(T)	<3.(T)
Ru			<0.06			<0.06			
Rh			<0.1			<0.1			
Pd			<0.6			<0.6			
Ag		<7.(T)	0.2		<5.(T)	0.6	<10.	<4.(T)	<3.(T)
Cd			4.			4.			
In			<0.1			<0.1			
Sn		70.	100.		30.	30.	50.	30.	20.
Sb			6.			8.			
Te			<0.4			<0.4			
I			<0.01			<0.01			
Cs			2.			2.			
Ba		60.	40.		60.	40.	100.	40.	30.
La			4.			4.			
Ce			6.			6.			
Pr			2.			2.			
Nd			6.			6.			
Sm			1.			1.			
Eu			0.1			0.1			
Gd			1.			1.			
Tb			0.2			0.2			
Dy			0.2			0.2			
Ho			0.2			0.2			
Er			<0.2			<0.2			
Tm			0.06			0.2			
Yb			0.2			<0.04			
Lu			<0.04			0.4			
Hf			0.2			<20.			
Ta			<20.			0.2			
W			0.2			<0.04			
Re			<0.04			<0.02			
Os			<0.02			<0.02			
Ir			<0.02			<0.06			
Pt			<0.06			<0.02			
Au		<2.	<0.02		<3.	<0.06	<3.	<3.	<3.
Hg			<0.06			0.06			
Tl			0.06			2,000.	8,000.	2,000.	2,000.
Pb	8,000.	5,000.	4,000.	5,900.	4,000.	2.			
Bi			1.			1.			
Th			0.2			0.6			
U			<0.2						
w/o factor[c]		2,550.			2,390.		4,500.	1,390.	1,270.

(a) Chem. = Wet chemical (primarily atomic absorption.)
(a) OES = Optical emission spectrographic.
(a) SSMS = Spark source mass spectrographic.
(b) T = Trace.
(c) Divide tabulated (ng/m³) value by factor to obtain weight percent.
_____Preferred value underlined.

TABLE 6. ANALYSIS OF AIR PARTICULATES ON MILLIPORE - CHICAGO
(Nanograms/m³)

	Sample Designation												
	000449			000450			000463				000464	000465	
Element	Chem.(a)	OES(a)	SSMS(a)	Chem.	OES	SSMS	Chem.	OES	SSMS	XRF	OES	OES	
Li			1.			1.			3.				
Be			0.03		◁.	0.03		◁20.(T)(b)	0.4		◁.(T)	◁10.(T)	
B			20.		30.	15.		50.	15.		20.	50.	
F	◁1,000.		60.	◁1,000.		20.	820.		250.				
Na	900.	1,000.		1,000.	700.		3,000.	800.	1,000.		500.	1,400.	
Mg	7,300.	6,000.		7,000.	4,000.		19,800	13,000.	15,000		5,000.	13,000.	
Al		6,000.			4,000.			8,000.	2,500	21,000	3,000.	6,000.	
Si		19,000.			13,000.			28,000.	25,000.	63,400.	9,000.	24,000.	
P			30.			20.			1,000.	700.			
S			1,000.			1,000.			2,000.	14,800.			
Cl			60.			50.	17,700.		600.	5,600.	12,800(c)	17,800(c)	
K	1,300.	6,000.		1,300.	1,400.		3,48%.	2,300	2,500.	7,800.	1,700.	2,600.	
Ca	19,650.	19,000.		15,300.	13,000.		44,000	26,000	30,000	49,400	9,000.	26,000.	
Sc			0.5			0.5			2.				
Ti		400.			400.			800.	600.	◁10.	300.	800.	
V		20.	20.		10.	10.		50.	40.		50.	300.	
Cr		40.	20.		30.	20.		50.	70.	200.	30.	30.	
Mn		100.			200.			20.	250.	1,000	2,000.	500.	
Fe	11,000	4,000.		11,800.	4,000.		20,200.	6,000.	10,000.	19,300.	3,000.	8,000.	
Co		◁.	◁0.6		◁.	1.		20.	0.7	130.	5.	10.	
Ni		60.	20.		10.	10.		20.	100.	200.	30.	100.	
Cu	300.	200.	150.	400.	300.	300.	1,300.	1,200.	1,500.	1,200.	500.	1,600.	
Zn	2,700.	1,000.	600.	1,600.	700.	500.	2,800.	500.	1,500.	2,000.	300.	2,600.	
Ga			0.6			0.4			2.	◁20.			
Ge			◁.			◁.			◁. (d)				
As			2.			2.			7.	3,300.			
Se			2.			2.			7.	20.			
Br			60.			20.			200	1,400.			
Rb			2.			2.			5.				
Sr			2.			2.			70.				
Y			2.			1.			15				
Zr		20.	15.		10.	10.		10.			20.	50.	
Nb			0.6			0.5							
Mo		◁.(T)	4.		◁.(T)	4.		◁20.(T)	5.		◁.(T)	◁10.(T)	
Ru			◁0.2			◁0.05			◁.				
Rh			◁0.1			◁0.05			◁0.5				
Pd			◁0.6			◁0.5			◁0.7				
Ag		6.	0.5		7.	0.3		◁20.(T)	◁.		◁.(T)	◁10.(T)	
Cd			3.			2.			◁.				
In			◁0.1			◁0.1			◁.				
Sn		50.	40.		40.	20.		80.	70.	40.	30.	100.	
Sb			6.			3.			10.				
Te			◁0.4			◁0.3			◁0.5	45.			
I			◁0.04			◁0.03			◁0.1		(e)		
Cs			1.			1.			0.2				
Ba		100.	100.		100.	100.		80.	250.	180.	50.	100.	
La			20.			20.			60.				
Ce			30.			30.			60.				
Pr			6.			5.			20.				
Nd			20.			15.			50.				
Sm			6.			3.			5.				
Eu			0.3			0.2			◁0.4				
Gd			2.			1.			◁.				
Tb			0.2			0.1			◁0.3				
Dy			0.6			0.3			1.				
Ho			0.06			0.03			◁0.3				
Er			0.2			0.1			◁.				
Tm			0.03			0.03			0.2				
Yb			0.2			0.1			◁.				
Lu			0.04			0.02			◁0.3				
Hf			0.1			0.1			0.5				
Ta			◁.			◁.			◁0.3				
W			0.2			0.1							
Re			◁0.006			◁0.006			◁0.05				
Os			◁0.01			◁0.01			◁0.1				
Ir			◁0.006			◁0.003			◁0.05				
Pt			◁0.02			◁0.02			◁0.1				
Au			◁0.02			◁0.02			◁0.3				
Hg		0.6	◁0.02		1.	0.05		◁1.(T)	◁0.2		◁1.(T)	◁1.(T)	
Tl			0.06						0.1				
Pb	9,100.	6,000.	4,000.	12,300.	7,000.	4,000.	3,000.	2,000.	10,000.	2,400	8,000.	2,000.	
Bi			0.6			0.5			3.				
Th			0.4			0.2			0.5				
U			0.2			0.2			0.5				
w/o factor(e)		2,370.			2,420.			5,140.			2,880.	4,160.	

(a) Chem. = Wet chemical (primarily atomic absorption).
(a) OES = Optical emission spectrographic.
(a) SSMS = Spark source mass spectrographic.
(a) XRF = X-ray fluorescence.
(b) T = Trace.
(c) Cl by wet chemical.
(d) Memory from previous samples.
(e) Divide tabulated (ng/m³) value by factor to obtain weight percent.
_____ Preferred value underlined.

TABLE 7. ANALYSIS OF AIR PARTICULATES ON GLASS - CINCINNATI
(Nanograms/m^3)

	Sample Designation													
	009269		009270		009254			009264			009266		
Element	Chem.	SSMS[a]	Chem.	SSMS	Chem.	SSMS	XRF[a]	Chem.	SSMS	XRF	Chem.	SSMS	XRF
H	3,460.		3,580.		3,900.			2,400.			2,300.		
Be		<0.02		<0.03		0.6			0.6			0.6	
C	23,400.		25,000.		20,000.			21,100.			15,600.		
N	1,880.		2,340.		2,500.			1,200.			1,200.		
Al							<10*			3,200.			250*
P		(b)		(b)		100.	<10.		300.	210.		500.	40.
S	5,700.	700*	6,600.	1,000.	7,400.	200*	9,600.	2,400.	300*	5,800.	3,700.	7,000.	6,500.
Cl	260.	(b)	280.	(b)	190.	100.	30.	1,200.	1,000.	3,200.	130.	100.	150.
K							<10*			2,400.			1,800.
Ca							<10*			7,500.			830.
Ti							40.			330.			130.
V							<10.			<10.			<3.
Cr							1,300*			160.			120.
Mn							460.			2,100*			120.
Fe							4,200.			24,000*			2,800.
Co							180*			50.			140*
Ni							230*			25.			25.
Cu		50.		100.			920.			320.			340.
Zn							740.			4,700.			960.
Ga		<2		3.		5.	460*		5.	<3.		3.	5.
As		(b)		5.		100	280.		30.	<3.		20.	<3.
Se		<2.		<2.		<15.	110*		<15.	<3.		15.	<3.
Br		30.		70.		150.	240.		600.	670.		100.	25.
Mo		0.6		0.7			1,800*			70.			80.
Ag		0.1		0.1									
Sn		7.		30.			20.			55.			50.
Sb		(b)		(b)		10.	<10.		20.	5.		40.	15.
Te		<0.03		<0.07		<2.	<10.		<2.	30.		<1.	15.
I		<0.2		0.7		10.			5.			2.	
Hg		<0.05		<0.1		<3.			<3.			<1.	
Tl		<0.02		<0.06		<0.5			<0.2			<0.4	
Pb		70*		400*		100*	420*		200*	2,200.		500.	1,400.
Bi		0.3		0.4		2.			2.			<1.	
w/o Factor[c]		910.	1,110.			810			1,080.			600.	

TABLE 7. ANALYSIS OF AIR PARTICULATES ON GLASS - CINCINNATI (con't)
(Nanograms/m^3)

Element	Sample Designation 009267 Chem.(a)	009267 SSMS(a)	009267 XRF(a)	009268 Chem.	009268 SSMS	009268 XRF	0010438 Chem.	0010438 XRF	0010439 Chem.	0010439 XRF	0010440 Chem.	0010440 XRF
H	3,000.			4,200.			2,200.		3,100.		4,100.	
Be		0.6			0.6							
C	1,900.			31,400.			19,400.		25,200.		27,800	
N	1,800.			2,500.		2,700.	1,900.		3,100		4,100	
Al			2,200.					2,900.			1,700.	
P		500.	165.		500.	270.		120.		120.		215.
S	4,600.	7,000.	8,200.	6,800.	15,000.	12,600.	2,900.	4,200.	4,100.	5,100.	5,900.	9,200.
Cl	370.	300.	660.	720.	1,000.	1,000.		2,000.		2,100.		1,300.
K			1,600.			1,600.		1,300.		970.		1,900.
Ca			2,200.			5,400.		6,000.		1,800.		6,300.
Ti			270.			400.		1,700.		310.		40.
V			8.			◁.		◁.		◁.		◁.
Cr			120.			65.		◁.		55.		120.
Mn			90.			100.		360.		110.		540.
Fe			5,200.			7,900.		5,600.		5,600.		8,100.
Co			◁.			10.		3.		25.		50.
Ni			3.			15.		7.		20.		30.
Cu			460.			500.		830.		260.		290.
Zn			1,800.			2,200.		1,100.		1,900.		590.
Ga	3.	◁.		10.		◁.		◁.		20.		40.
As	20.	◁.		60.		◁.		◁.		360*		360*
Se	15.	◁.		≤15.		◁.						
Br	100.	30.		1,000.		540.		600.		1,000.		1,100.
Mo		◁.				◁.		100.		150.		140.
Ag												
Sn		80.				60.		50.		110.		60.
Sb	40.	1.		40.		◁.		◁.		10.		25.
Te	≤2.	◁.		≤1.		10.		8.		8.		15.
I	4.			10.								
Hg	◁1.			◁1.								
Tl	≤1.			≤1.								
Pb	2,000.	1,600.		3,000.	2,500.		1,400.		3,300.		3,200.	
Bi	4.			4.								
w/o Factor(c)	830.			1,210.			820.		1,030.		1,070.	

(a) Chem. = Combustion and wet chemical.
(a) SSMS = Spark-source mass spectrographic.
(a) XRF = X-ray fluorescence.
(b) Concentration in sample is ≤ than in blank.
(c) Divide tabulated value (ng/m^3) by factor to obtain weight percent.
_____ Preferred value underlined.
* Value extremely doubtful.

TABLE 8. ANALYSIS OF AIR PARTICULATES ON GLASS - DENVER
(Nanograms/m3)

Element	Sample Designation 0010290 Chem.(a)	0010290 SSMS(a)	0010290 XRF(a)	0010289 Chem.	0010289 XRF	0010291 Chem.	0010291 XRF	0010319 Chem.	0010319 XRF
H	2,800.			4,200.		4,800.		7,600.	
Be		0.6							
C	24,100.			36,300.		40,500.		66,500.	
N	1,100			1,700.		1,500.		2,400.	
Al			3,600.		7,600.		8,200.		10,000.
P			130.		190.		220.		340.
S		100.	1,500.		2,200.		3,000.		3,200.
Cl	1,500.	2,000.	960.	1,600.	2,300.	2,600.	3,000.	2,500.	2,800.
K	650.	1,000.	2,600.		4,400.		5,300.		7,000.
Ca			◁*		2,500.		2,200.		1,800.
Ti			300.		460.		530.		660.
V			8.		◁.		◁.		◁.
Cr			180.		◁.		30.		75.
Mn			70.		90.		150.		240.
Fe			4,400.		6,700.		7,500.		10,000.
Co			9.		5.		8.		11.
Ni			30.		◁.		7.		11.
Cu			520.		210.		260.		360.
Zn			230.		380.		400.		700.
Ga			6.		◁.		◁.		◁.
As		10.	6.		190*		430*		540*
Se		30.	◁.						
Br		≤10.	810.		1,300.		1,200.		1,900.
Mo		1,000.	145.		40.		100.		140.
Ag									
Sn			12.		10.		14.		10.
Sb		10.	3.		◁.		◁.		◁.
Te		≤1.	◁.		◁.		◁.		◁.
I		2.							
Hg		◁.							
Tl		1.							
Pb		6,000.	2,400.		3,500.		4,000.		5,100.
Bi		4.							
w/o factor(c)		1,100.		1,410.		1,880.		2,020.	

TABLE 8. ANALYSIS OF AIR PARTICULATES ON GLASS - DENVER (con't)
(Nanograms/m^3)

Element	Sample Designation 0013888 Chem.(a)	0013888 SSMS	0013871 Chem.	0013871 SSMS	009179 Chem.	009179 SSMS	009179 XRF	0010265 Chem.	0010265 SSMS	0010265 XRF
H	3,770.		3,590.		3,600.			4,400.		
Be		<0.04		<0.03		0.6			0.6	
C	31,700.		29,800.		30,000.			36,500.		
N	1,540.		1,640.		1,500.			1,600.		
Al							4,200.			9,000.
P		(b)		(b)		300.	200.		500.	200.
S	1,800.	400.	1,900.	150*	2,300.	7,000.	3,100.	1,800.	2,000.	2,200.
Cl	310.	40*	450.	(b)	790.	2,000.	960.	710.	1,000.	1,500.
K							2,900.			5,400.
Ca							1,000.			750.
Ti							300.			500.
V							<3.			<3.
Cr							50.		40.	
Mn							<3.			10.
Fe							4,600.			10,000.
Co							<3.			<3.
Ni							10.			10.
Cu		100.		400.			1,000.			1,200.
Zn							160.			180.
Ga		0.4		0.6		6.	<3.		1.	<3.
As		(b)		(b)		10.	<3.		30.	<3.
Se		0.7		<0.7		<5.	<3.		<10.	<3.
Br		100.		20.		800.	630.		1,000.	940.
Mo		2.		6.			<3.			16.
Ag		0.4		1.						
Sn		2.		3.			4.			7.
Sb		(b)		(b)		4.	<3.		10.	<3.
Te		<0.06		<0.04		<2.	<3.		<3.	<3.
I		0.7		0.3		2.			2.	
Hg		<0.06		<0.1		<1.			<4.	
Tl		<0.1		<0.04		<0.4			<0.4	
Pb		5,000.		400*		2,000.	1,600.		6,000.	2,300.
Bi		0.1		0.1		1.			4.	
w/o factor(c)	1,120.		1,220.		1,160.				1,540.	

(a) Chem. = combustion and wet chemical.
(a) SSMS = Spark source mass spectrographic.
(a) XRF = X-ray fluorescence.
(b) Concentration in sample ≤ than in blank
(c) Divide tabulated value (ng/m^3) by factor to obtain weight percent.
* Value extremely doubtful.
_____ Preferred value underlined.

TABLE 9. ANALYSIS OF AIR PARTICULATES ON GLASS - ST. LOUIS
(Nanograms/m^3)

	Sample Designation								
	009066		009071		009084		0010142		
Element	Chem.[a]	SSMS[a]	Chem.	SSMS	Chem.	SSMS	Chem.	SSMS	XRF[a]
H	3,700.		3,750.		6,560.		3,200.		
Be		<0.05		<0.03		(b)		0.6	
C	25,800.		29,600.		38,600.	26,400.			
N	2,110.		1,630.		4,630.		1,300.		
Al									1,250.
P		30.		(b)		100.		500.	270.
S	8,000.	1,000.	6,000.	300*	14,000.	5,000.	5,800.	7,000.	8,000.
Cl	480.	(b)	1,180.	(b)	430.	(b)	1,000.	1,000.	1,800.
K									1,000.
Ca									12,000.
Ti									300.
V									<3.
Cr									60.
Mn									100.
Fe									420.
Co									<3.
Ni									14.
Cu		100.		70.		400.			450.
Zn									680.
Ga		1.		<2.		3.		3.	<3.
As		(b)		(b)		(b)		20.	<3.
Se		3.		≤1.		2.		≤15.	<3.
Br		15.		40.		20.		500.	480.
Mo		2.		0.7.		1.			4.
Ag		1.		0.5		2.			
Sn		15.		15.		20.		25.	
Sb		(b)		(b)		(b)		4.	<3.
Te		≤0.2		<0.04		≤0.1		≤2.	21.
I		0.5		0.5		0.1		2.	
Hg		<0.1		<0.1		<0.2		<1.	
Tl		≤0.03		<0.07		<0.04		<0.4	
Pb		150*		2,000.		600.		2,000.	2,300.
Bi		0.3		≤0.1		0.2		<1.	
w/o factor[c]	1,430.		1,220.		1,790.		1,110.		

TABLE 9. ANALYSIS OF AIR PARTICULATES ON GLASS - ST. LOUIS (con't)
(Nanograms/m^3)

	Sample Designation											
	0010146			0010154			0010161		0010168		0010174	
Element	Chem.(a)	SSMS(a)	XRF(a)	Chem.	SSMS	XRF	Chem.	XRF	Chem.	XRF	Chem.	XRF
H	4,000.			2,800.			3,200.		6,000.		2,900.	
Be		0.6			2.							
C	31,900.			25,400.			25,500.		45,300.		29,700.	
N	1,900.			1,100.			1,700.		4,300.		1,300.	
Al			2,400.			3,200.		3,000.		3,600.		1,800.
P		500.	430.		500.	320.		50.		80.		45.
S	5,200.	6,000.	6,000.	4,000.	10,000.	6,200.	4,900.	8,100.	11,700.	19,000.	2,800.	4,800.
Cl	1,900.	1,000.	3,500.	1,700.	3,000.	2,900.		3,500.		6,600.		2,600.
K			1,700.			1,300.		1,600.		1,900.		1,600.
Ca			14,000.			13,000.		15,000.		28,000.		24,000.
Ti			275.			225.		270.		370.		840.
V			◁.			◁.		◁.		◁.		◁.
Cr			26.			110.		◁.		◁.		◁.
Mn			30.			90.		90.		5.		120.
Fe			5,100.			4,200.		5,300.		720.		4,800.
Co			◁.			10.		5.		◁.		◁.
Ni			9.			35.		2.		2.		◁.
Cu			720.			175.		730.		3,100*		5,800.
Zn			2,100.			1,400.		850.		2,400.		500.
Ga		3.	◁.		3.	◁.		◁.		◁.		◁.
As		10.	◁.		200*	10.		125*		1,400*		740*
Se		≤10.	◁.		20*	◁.						
Br		300.	550.		1,000.	830.		700.		100.		950.
Mo			9.			210.		35.		◁.		36.
Ag												
Sn			120*			120*		8.		630*		50.
Sb		10.	14.		10.	3.		◁.		75*		8.
Te		≤2.	32*		≤4.	32*		◁.		70*		60.
I		0.6			2.							
Hg		<1.			◁.							
Tl		≤0.4			≤0.4							
Pb		6,000.	3,600.		6,000.	3,800.		3,000.		5,100.		3,400.
Bi		4.			4.							
w/o factor(c)	1,250.		1,170.		1,170.	1,170.		1,970.		1,150.		

(a) Chem. = Combustion and wet chemical.
(a) SSMS = Spark-source mass spectrographic.
(a) XRF = X-ray fluorescence.
(b) Concentration in sample is ≤ than in blank.
(c) Divide tabulated (ng/m^3) value by factor to obtain weight percent.
Preferred value underlined.
* Value extremely doubtful.

TABLE 10. ANALYSIS OF AIR PARTICULATES ON GLASS - WASHINGTON
(Nanograms/m^3)

	Sample Designation													
	008978		009008			009009			009012			009018		
Element	Chem[a]	SSMS[a]	Chem	SSMS	XRF[a]	Chem	SSMS	XRF	Chem	SSMS	XRF	Chem	SSMS	XRF
H	2,100		7,600			2,600			3,300			5,300		
Be		<0.03		0.2			0.6			≤0.06			0.2	
C	14,700		41,000			16,200			19,100			27,100		
N	1,640		7,000			2,300			700			4,200		
Al					360			300			<10*			<10*
P		(b)		20	<10		100	100		30	<10		50	<10
S	4,100	700*	18,000	3,000*	23,000	5,900	7,000	8,200	5,500	1,000*	4,600	12,200	2,000	15,000
Cl	67	(b)	680	100	<10*	270	100	50	480	30	<10*	380	30	<10
K					<10*			1,100			<10*			<10*
Ca					<10*			400*			<10*			<10*
Ti					230			380			110			<10*
V					250			70			<10*			<10*
Cr					720*			135*			550*			860*
Mn					<10			<10			<10			<10
Fe					2,300			2,700			2,000			2,500
Co					45*			<10			<10			<10
Ni					160			35			140			230
Cu		350			2,800			750			1,300			1,150
Zn					<10*			100			<10*			<10*
Ga		0.5		1	45*		6	<10		3	<10		1	<10
As		(b)		6	<10		10	<10		10	<10		6	<10
Se		≤0.4		≤3	<10		≤15	<10		≤15	<10		≤3	<10
Br		15		20			200	100		40	<10		20	<10
Mo		0.2		<10	250*			50*			<10			380*
Ag		0.2												
Sn		7			20			20			130*			<10
Sb		(b)		4	<10		10	<10		10	<10		4	<10
Te		<0.04		<1	<10		<0.4	<10		<0.2	<10		<1	<10
I		0.2		1			2			1			1	
Hg		<0.04		<1			<1			<1			<1	
Te		<0.03		<0.2			<0.4			<0.2			<0.2	
Pb		700		1,000	3,000		1,000	1,200		300	120		500	630
Bi		0.2		<1			1			<1			<1	
w/o factor[c]		660		1,540			820			880			1,060	

TABLE 10. ANALYSIS OF AIR PARTICULATES ON GLASS - WASHINGTON (con't)
(Nanograms/m^3)

	Sample Designation											
	009027			009028			0010114		0010117		0010136	
Element	Chem	SSMS	XRF	Chem	SSMS	XRF	Chem	XRF	Chem	XRF	Chem	XRF
H	6,200			3,500			1,700		2,600		1,700	
Be		2			0.2							
C	48,400			19,600			13,500		14,000		12,300	
N	4,700			1,700			1,100		300		1,000	
Al			8,600			<10*		1,100		<10*		2,600
P		500	380		50	<10		8		<10		8
S	8,600	6,000	16,000	6,100	2,000	6,200	2,900	3,900	3,300	2,900	3,200	4,900
Cl	830	30	60	250	30	<10		820		800		520
K			3,500			<10*		510		25*		1,600
Ca			2,500			<10*		740		3,600		1,900
Ti			840			230		300		70		390
V			240			180		94		70		44
Cr			60			970		130		120		<2
Mn			<3			175		190		20		70
Fe			9,500			2,200		1,500		400		2,600
Co			<3			115*		25		45*		<2
Ni			60			200		90		90		40
Cu			840			1,950		100		280		260
Zn			340			<10*		330		<10*		80
Ga		3	<3		1	<10		30*		400*		<3
As		30	<3		<3	<10		700*		2,900*		80
Se		20*	<3		20	<10		720		800		520
Br		200	760			<10		410*		1,000*		100*
Mo			<3			1,200*						
Ag								20		25		8
Sn			25			35		90*		105*		<3
Sb		40	<10		4	<10		6		25		<3
Te		<2	<3		<3	<10						
I		3			1							
Hg		<3			<3							
Te		<0.4			<0.2							
Pb		2,000	4,800		500	175		1,000		700		1,300
Bi		<3			<3			490		370		660
w/o factor(c)	4	1,920			990							

(a) Chem = combustion and wet chemical
(a) SSMS = spark-source mass spectrographic
(a) XRF = X-ray fluorescence
(b) Concentration in sample is $\leq$ than in blank
(c) Divide tabulated value (ng/m^3) by factor to obtain weight percent
* Value extremely doubtful
_____Preferred value underlined.

TABLE 11. ANALYSIS OF AIR PARTICULATES ON GLASS - CHICAGO
(Nanograms/m^3)

	Sample Designation											
	009273			009275			009278		009286		009299	
Element	Chem(a)	SSMS(a)	XRF(a)	Chem	SSMS	XRF	Chem	XRF	Chem	XRF	Chem	XRF
H	10,900.			8,800.			12,200.		6,100.		11,000.	
Be		0.6			0.6							
C	97,600.			57,100.			111,000.		53,700.		103,000.	
N	4,100.			7,800.			6,200.		4,400.		10,600.	
Al			11,000.			3,800.		11,300.		6,000.		7,300.
P		500.	615.		500.	450.		800.		300.		650.
S	11,500.	1,000.*	26,000.	15,100.	3,000.	50,000.	19,500.	15,500.	7,900.	13,700.	11,700.	19,900.
Cl	5,100.	5,000.	6,800.	1,200.	1,000.	940.		8,400.		5,700.		11,200.
K			8,200.			2,900.		8,000.		4,000.		4,600.
Ca			38,000.			1,600.		42,000.		22,000.		28,000.
Ti			940.			580.		830.		520.		600.
V			<3.			<3.		<10.		<10.		100.
Cr			<3.			35.		250.		55.		140.
Mn			140.			25.		470.		480.		520.
Fe			17,000.			11,000.		17,200.		13,400.		15,100.
Co			<3.			<3.		60.		40.		35.
Ni			<3.			12.		80.		50.		120.
Cu			570.			640.		450.		1,300.		1,800.
Zn			2,700.			400.		1,400.		1,500.		3,000.
Ga		5.	<3.		5.	<3.		<10.		<10.		<10
As		30.	<3.		30.	<3.		1,200.		880.		1,200.
Se		<15.	<3.		<15.	<3.						
Br		2,000.	3,100.		2,000.	2,600.		4,000.		2,600.		4,500.
Mo			<3.			40.		500.		210.		220.
Ag												
Sn			120.			35.		100.		60.		100.
Sb		40.	40.		20.	4.		65.		40.		25.
Te		<2.	80.*		<4.	12.*		90.*		55.*		30.*
I		10.			10.							
Hg		<1.			<1.							
Tl		1.			<0.2							
Pb		700.	17,000.		700.	16,000.		12,000.		8,500.		14,400.
Bi		6.			1.							
w/o factor(b)		4,030.			2,420.			3,840.		2,320.		3,080.

* Value extremely doubtful.
(a) Chem = combustion and wet chemical. (a) SSMS = spark-source mass spectrographic. (a) XRF = X-ray fluorescence.
(b) Divide tabulated value ($^{n}g/m^3$) by factor to obtain weight percent.
_ Preferred value underlined.

TABLE 12. ANALYSIS OF AIR PARTICULATES ON GLASS - PHILADELPHIA (Nanograms/m^3)

	Sample Designation			
	009150		009125	
Element	Chem(a)	SSMS(a)	Chem	SSMS
H	4,070.		5,230.	
Be		<0.03		<0.04
C	29,700.		29,000.	
N	3,070.		5,870.	
F		(b)		(b)
P		(b)		30.
S	7,700.	4,000.	12,000.	1,500.
Cl	320.	(b)	190.	(b)
Cu		70.		100.
Ga		0.4		1.
As		(b)		4.
Se		1.		3.
Br		40.		50.
Mo		0.4		3.
Ag		0.3		0.4
Sn		5.		15.
Sb		15.		150.
Te		<0.04		<0.07
I		0.3		0.4
Hg		<0.1		<0.07
Tl		<0.04		<0.04
Pb		300.		2,000.
Bi		0.2		0.4
w/o Factor(c)	1,450.			1,400.

(a) Chem = combustion and wet chemical. SSMS = spark-source mass spectrographic analysis.
(b) Concentration in sample is $\leq$ than in blank.
(c) Divide tabulated value (ng/m^3) by factor to obtain weight percent.
— Preferred value underlined.

TABLE 13. ANALYSIS OF AIR PARTICULATES FOR MERCURY
(Nanograms/m^3)

City	Filter Number	Hg OES(a)	Hg SSMS(b)	Hg SSMS(c)
Cincinnati				
	009269	1.5(d)	<0.05	
	009270	0.3(d)	<0.1	
	009254	<1.8		
	009264	<0.3		
	009266	<0.3		<0.01
	009267	<0.3		<0.01
	009268	0.7		<0.01
	0010438	<0.3		
	0010439	<0.3(T)		
	0010440	0.3		
Denver				
	0013888	1.4(d)	<0.06	
	0013871	2. (d)	<0.1	
	009179	3.4		<0.03
	0010265	1.7		<0.05
	0010290	1.7		<0.1
	0010289	1.		
	0010291	2.		
	0010319	3.5		
St. Louis				
	009066	0.3(d)	<0.1	
	009071	<0.3(d)	<0.1	
	009084	<0.4	<0.2	
	0010142	<0.3		<0.06
	0010146	<0.3		<0.06
	0010154	<0.3		<0.06
	0010161	<0.3(T)		
	0010168	<0.6		
	0010174	<0.3(T)		
Washington				
	008978	<0.3(d)	<0.04	
	009008	<1.8		
	009009	<0.3		<0.06
	009012	<1.8		
	009018	<1.8		<0.06
	009027	<0.4		
	009028	<1.8		
	0010114	<0.6(T)		

TABLE 13. (Continued)

City	Filter Number	Hg OES(a)	Hg SSMS(b)	Hg SSMS(c)
	0010117	<2.4(T)		
	0010136	<0.4(T)		
Chicago				
	009273	1.2		<0.02
	009275	2.1		<0.02
	009278	0.8		
	009286	0.5		
	009299	0.8		
Philadelphia				
	009150	3.5(d)	<0.1	
	009125	2.5(d)	<0.07	
Cincinnati(e)				
	-	3.	<2.	

(a) OES = optical emission spectrography--"boiler cap" (glass filters).
(b) SSMS = spark source mass spectrography (glass filters).
(c) SSMS = spark source mass spectrography (Millipore filters).
(d) Duplicate analysis gave the same result as shown.
(e) Silver filter.
(T) = trace.

TABLE 14. ANALYSIS OF AIR PARTICULATES ON SILVER - CINCINNATI
(Nanograms/m^3)

Element	Chem[a] As Rec'd	Chem[a] After C_6H_6	OES[a] As Rec'd	OES[a] Blank	SSMS[a] As Rec'd	SSMS[a] Ashed[b]	Best Estimate ng/m^3	Best Estimate w/o
H	1,600.	1,100.					1,600.	2.4
Li			15.	<7.	0.1	0.1	0.1	0.0001
Be					3.	3.	3.	0.004
B			7.	<7.			7.	0.01
C	12,500.	9,400.					12,500.	18.4
N	1,500.	1,500.					1,500.	2.3
O							20,000.	29.7(c)
F					600.	600.	600.	0.9
Na	1,300.		1,400.	35.			1,300.	1.9
Mg	560.		500.	7.			560.	.8
Al			500.	150.			500.	.7
Si			4,200.	700.			4,200.	6.2
P					30.	30.	30.	0.04
S	2,900.	2,900.			1,000.	1,000.	2,900.	4.3
Cl					2,000.	2,000.	2,000.	2.9
K	450.		1,400.	<50.			500.	0.7
Ca	1,900.		500.	<7.(T)			1,900.	2.8
Ti			20.	<7.			20.	0.03
V			<7.(T)	<7.				
Cr			7.	<7.			7.	0.01
Mn			150.	<7.			150.	0.2
Fe	1,400.		2,100.	<7.(T)			1,500.	2.3
Ni			20.	<7.(T)			20.	0.03
Cu	50.		20.	<7.			50.	0.07
Zn	330		200.	<7.			330.	0.5
Ga					1.	1.	1.	0.001
As					20.	20.	20.	0.03
Se					<3.	<3.		
Br					600.	100.	600.	0.9
Rb					2.	2.	2.	0.003
Sr					10.	10.	10.	0.01
Y					0.4	0.4	0.4	0.0006
Zr					20.	20.	20.	0.03
Mo			70.	<7.			70.	0.1
Sn			7.	<7.	4.	4.	7.	0.01
Te					<0.4	<0.4		
I					4.	4.	4.	0.006
Ba			7.	<7.			7.	0.01
Hg			3.	0.6	<2.	<0.6	3.	0.004
Tl					<0.2	<0.2		
Pb	970.		1,400.	7.	1,500.	1,500.	1,000.	1.5
Bi			<7.(T)	<7.	2.	2.	2.	0.003
Total								79.8

T = Trace.
(a) Chem = Combustion and wet chemical.
(a) OES = Optical emission spectrographic.
(a) SSMS = Spark-source mass spectrographic.
(b) Ignited in air @ 300 C for 3 hr.
(c) See Table 15. Percentage oxygen based on C_6H_6 extracted sample (98.1 percent of total sample.

TABLE 15. ANALYSIS OF SILVER FILTER FOR OXYGEN COMPOUNDS

Compound		Volume Percent of Gas Fraction	Weight Percent Oxygen on Particulate Basis[a]
Sample A			
100 C fraction			
C_6H_6		0.06	-
SO_2		0.09	0.00564
CO_2		0.65	0.0395
NO		0.61	0.0185
N_2		0.31	-
F_2		1.46	-
H_2O		96.8	2.95
	Totals	100.	3.02
500 C fraction			
C_6H_6		0.10	-
SO_2		5.48	0.48
CO_2		44.9	3.92
NO		12.7	0.54
CO		9.90	0.43
C_3H_6		0.29	-
C_2H_4		0.27	-
H_2		0.13	-
H_2O		26.2	1.50
	Totals	100.	6.87
1700 C fraction (Vacuum fusion)			
SO_2		0.29	0.090
CO_2		14.6	4.40
COS		0.05	0.007
CO		84.8	12.7
O_2		0.19	0.055
CH_4		0.02	-
H_2		0.01	-
	Totals	100.	17.25
	Overall total	-	27.14
Sample B			
Vacuum fusion (1700 C)			
C_6H_6		0.14	-
SO_2		1.29	0.63
COS		0.04	0.01
CO_2		24.2	11.8
H_2O		3.41	0.83
NO		4.05	1.00
CO		63.3	15.4
C_2H_4		0.70	-
H_2		2.51	-
CS_2		0.14	-
C_3 hydrocarbons		0.26	-
	Totals	100.	29.67

(a) Particulate after C_6H_6 extraction. C_6H_6 extraction removed about 1.9 percent of the sample.

COMPOUND IDENTIFICATION

Quantitative X-Ray Diffraction

Certain compounds, as distinguished from elements, appear to have more severe health effects than do other compounds of the same elements. One such case is believed to be α-Quartz, which is thought to be more toxic than, for example, silicates. For this reason, and because Si (presumably much of its present as SiO_2) is a major component of the air particulates examined and thus offers a favorable case, α-Quartz was chosen for the development of a quantitative method to determine specific compounds.

After several false starts, a procedure was developed that appears promising, although it cannot be claimed that all the problems are solved. There do not seem to be any obvious flaws in the technique, yet two samples, presumably duplicates with a minor exception (the filter diameter) gave results with a spread of almost a factor of four. The sample refiltered on the larger diameter filter gave results more nearly logical in view of the very high Si content of the sample. Therefore, on the basis of one experiment it may be that a large area is necessary to avoid a "thick" sample with its attendant problems of absorption, fluorescence, etc.

The method employed for the work reported in Table 16 is outlined below.

(1) Prepare synthetic standards using $CaCO_3$ with varying amounts of α-Quartz.

(2) Add NiO as the internal standard.

(3) Determine the ratio $\frac{I_{SiO_2}}{I_{NiO}}$ (d_{SiO_2} = 3.34 Å, d_{NiO} = 2.40 Å).

Plot this ratio as a function of the concentration of SiO_2.

TABLE 16. X-RAY DIFFRACTION ESTIMATION OF α-QUARTZ (Weight Percent)

Sample	Total Si[(a)]	α-Quartz
Cincinnati		
000451	7.8	1.
000452	10.	1.
Chicago		
000463	5.	5.
Denver		
000475	25.	3.(b)
St. Louis		
000501	15.	2.

(a) Multiply by 2.1 for equivalent SiO_2.
(b) 11 percent found in another run using 25-mm filters. 10-mm filters used in all other cases.

(4) Ultrasonically shake the particles from 1 cm^2 weighed filter sample using H_2O. Add 0.500 mg NiO as internal standard. Filter on 0.8 μm pore Millipore filter. (10-mm-diameter filters were used for all but one run; 25-mm diameter may be preferable.)

(5) Mount the filter with 1 percent collodion in amyl alcohol.

(6) Determine $\frac{I_{SiO_2}}{I_{NiO}}$ as before, and read the concentration of the SiO_2 from the previously prepared standards plot.

The results of these experiments are given in Table 16.

Qualitative X-Ray Diffraction

The results obtained from the XRD examinations of unseparated and density/magnetically separtated fractions of particulates collected in four cities are shown in Table 17. To get a general analysis of the major compounds present in each city, a portion of the particulate sample was scraped from the all-nylon Millipore filters and run in a Debye-Scherrer X-ray diffraction camera. In many cases these samples were run in both the large and small cameras in order to help separate lines or bring their intensity up to a level where their position could be established more accurately. Special mounting techniques using 8- to 10-micron glass fibers as the sample substrate and a thin film of Vaseline to bind the particles to the substrate were employed. This technique produced a sample less than 100 microns in diameter, greatly enhancing the possibility of separating groups of closely spaced lines and providing more information about

TABLE 17. COMPOUNDS IDENTIFIED IN PARTICULATE SAMPLES AND THEIR X-RAY DIFFRACTION PATTERN STRENGTH

Filter Sample Number and City	Compound	X-Ray Pattern Strength
000451 Cincinnati		
Unseparated		
	SiO_2 (α-Quartz)	Strong
	$CaCO_3$ (Calcite)	Medium
	Fe_3O_4 (Magnetite)	Medium
	$(NH_4)_2Ni(SO_4)_2 \cdot 6H_2O$	Medium
	$CaMg(CO_3)_2$ (Dolomite)	Weak
	α-FeO (OH) (Goethite)	Weak
	Fe (α-Iron)	Very weak
	α-Fe_2O_3 (Hematite)	Very weak
	Possible clay minerals and copper compounds with oxygen and/or sulfur	
Separated Magnetic		
	Fe_3O_4 (Magnetite)	Very strong
	α-Fe_2O_3 (Hematite)	Medium weak
	Fe (α-Iron)	Weak
	FeO (Wustite)	Very weak
	SiO_2 (α-Quartz)	Very weak
Density <0.79		
	No Identifiable Compounds	
Density 0.79-1.59		
	$CaCO_3$ (Calcite)	Strong
	SiO_2 (α-Quartz)	Medium
	Fe_3O_4 (magnetite)	Medium weak
Density 1.59-2.8		
	SiO_2 (α-Quartz)	Strong
	$CaMg(CO_3)_2$ (Dolomite)	Medium
	Fe_3O_4 (Magnetite)	Medium
	PbSO4 (Anglesite)	Weak
Density >2.8		
	Fe_3O_4 (Magnetite)	Strong
	SiO_2 (α-Quartz)	Medium

TABLE 17. (Continued)

Filter Sample Number and City	Compound	X-Ray Pattern Strength
000452 Cincinnati		
Unseparated		
	SiO_2 (α-Quartz)	Strong
	Fe_3O_4 (Magnetite)	Medium
	$CaSO_4 \cdot 2H_2O$ (Gypsum)	Medium
Separated		
Magnetic		
	Fe_3O_4 (Magnetite)	Strong
	α-Fe_2O_3 (Hematite)	Weak
	Fe (α-Iron)	Very weak
	FeO (OH) (Goethite)	Very weak
	SiO_2 (α-Quartz)	Very weak
Density <0.79		
	SiO_2 (α-Quartz)	Strong
	$PbSO_4$ (Anglesite)	Medium
	Fe_3O_4 (Magnetite)	Weak
Density 0.79-1.59		
	SiO_2 (α-Quartz)	Strong
	$PbSO_4$ (Anglesite)	Medium
	Fe_3O_4 (Magnetite)	Medium
	α-Fe_2O_3 (Hematite)	Very weak
	PbO (Litharge)	Very weak
Density 1.59-2.8		
	SiO_2 (α-Quartz)	Strong
	$PbSO_4$ (Anglesite)	Weak
	Fe_3O_4 (Magnetite)	Weak
	α-Fe_2O_3 (Hematite)	Very weak
	Kaolinite	Very weak
Density >2.8		
	SiO_2 (α-Quartz)	Very strong
	$PbSO_4$ (Anglesite)	Strong
	Fe_3O_4 (Magnetite)	Strong
	α-Fe_2O_3 (Hematite)	Medium
	$CaMg(CO_3)_2$ (Dolomite)	Weak
H_2O Soluble	Analysis of the dried down water leach showed that the major ions present are: calcium, sodium, sulfate, carbonate, and chloride.	

TABLE 17. (Continued)

Filter Sample Number and City	Compound	X-Ray Pattern Strength
000475 Denver		
Unseparated		
	SiO_2 (α-Quartz)	Very strong
	$CaCO_3$ (Calcite)	Weak
	$CaMg(CO_3)_2$ (Dolomite)	Weak
	Illite	Weak
	$Mg_5Si_8O_{20}(OH)_2 \cdot 8H_2O$ (Palygorskite)	Weak
	Fe_3O_4 (Magnetite)	Very weak
	α-Fe_2O_3 (Hematite)	Very weak
	$NaAlSi_3O_8$ (Albite)	Very weak
	$CaSO_4 \cdot 2H_2O$ (Gypsum)	Very weak
	(Anorthoclase)	
	γ-$Al_2O_3 \cdot H_2O$ (Bohemite)	Very weak
	Possible other clay mineral and feldspar group compounds present	
Separated		
Magnetic		
	Fe_3O_4 (Magnetite)	Very strong
	α-Fe_2O_3 (Hematite)	Medium
	Fe (α-Iron)	Medium
	SiO_2 (α-Quartz)	Weak
	FeO(OH) (Goethite)	Very weak
Density <0.79		
	SiO_2 (α-Quartz)	Strong
	Bavalite (Chlorite)	Medium
	$CaMg(CO_3)_2$ (Dolomite)	Weak
Density 0.79-1.59		
	SiO_2 (α-Quartz)	Strong
	$CaMg(CO_3)_2$ (Dolomite)	Very weak
	$CaSO_4 \cdot 2H_2O$ (Gypsum)	Very weak
Density 1.59-2.8		
	SiO_2 (α-Quartz)	Strong
	$Mg_5Si_8O_{20}(OH)_2 \cdot 8H_2O$ (Palygorskite)	Very weak
Density >2.8		
	SiO_2 (α-Quartz)	Strong
	$Mg_5Si_8O_{20}(OH)_2 \cdot 8H_2O$ (Palygorskite)	Very weak
	α-Fe_2O_3 (Hematite)	Very weak
	$CaCO_3$ (Calcite)	Very weak
H_2O Soluble	Analysis of the dried water leach showed that the major ions present are: calcium, sodium, sulfate, carbonate, and chloride.	

TABLE 17. (Continued)

Filter Sample Number and City	Compound	X-Ray Pattern Strength
000501 St. Louis		
Unseparated		
	SiO_2 (α-Quartz)	Strong
	$CaSO_4 \cdot 2H_2O$ (Gypsum)	Medium
	$CaCO_3$ (Calcite)	Very weak
	$CaCO_3$ (Aragonite)	Very weak
	Muscovite	Very weak
	Kaolinite	Very weak
Separated		
Density <0.79		
	SiO_2 (α-Quartz)	Strong
	Fe_3O_4 (Magnetite)	Weak
Density 0.79-1.59		
	SiO_2 (α-Quartz)	Strong
	$CaCO_3$ (Calcite)	Medium
	Fe_3O_4 (Magnetite)	Very weak
Density 1.59-2.8		
	SiO_2 (α-Quartz)	Very strong
	$CaCO_3$ (Calcite)	Medium
	$CaMg(CO_3)_2$ (Dolomite)	Medium
	$K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$ (Muscovite)	Weak
Density >2.8		
	SiO_2 (α-Quartz)	Very strong
	$CaMg(CO_3)_2$ (Dolomite)	Strong
	Fe_3O_4 (Magnetite)	Medium
	α-Fe_2O_3 (Hematite)	Weak
H_2O Soluble		
	$CaSO_4 \cdot 2H_2O$ (Gypsum)	Strong
	NaCl (Halite)	Weak
	$2CaSO_4 \cdot H_2O$ (Bassanite)	Very weak

TABLE 17. (Continued)

Filter Sample Number and City	Compound	X-Ray Pattern Strength
000463 Chicago		
Unseparated		
	SiO_2 (α-Quartz)	Strong
	$CaMg(CO_3)_2$ (Dolomite)	Medium
	$CaSO_4 \cdot 2H_2O$ (Gypsum)	Medium
	α-Fe_2O_3 (Hematite)	Weak
	Fe_3O_4 (Magnetite)	Very weak
	$CaCO_3$ (Calcite)	Very weak
	Illite	Very weak
Separated		
Magnetic		
	Fe_3O_4 (Magnetite)	Very strong
	α-Fe_2O_3 (Hematite)	Medium weak
	Fe (α-Iron)	Weak
	FeO (Wustite)	Weak
	α-FeO(OH) (Goethite)	Very weak
	SiO_2 (α-Quartz)	Very weak
	$CaMg(CO_3)_2$ (Dolomite)	Very weak
Density <0.79		
	No Identifiable Compounds	
Density 0.79-1.59		
	SiO_2 (α-Quartz)	Medium
	Unknown	Medium
Density 1.59-2.8		
	SiO_2 (α-Quartz)	Strong
	$CaMg(CO_3)_2$ (Dolomite)	Strong
	$Al_2(SO_4)_3 \cdot 18H_2O$	Weak
Density >2.8		
	SiO_2 (α-Quartz)	Strong
	$CaMg(CO_3)_2$ (Dolomite)	Strong

TABLE 17. (Continued)

Filter Sample Number and City	Compound	X-Ray Pattern Strength
000500 St. Louis		
Unseparated	SiO_2 (α-Quartz)	Very strong
	$CaCO_3$ (Calcite)	Strong
	$CaMg(CO_3)_2$ (Dolomite)	Medium
	Fe_3O_4 (Magnetite)	Weak
	α-Fe_2O_3 (Hematite)	Weak
	Possible clay minerals present	
Separated Magnetic	Fe (α-Iron)	Strong
	Fe_3O_4 (Magnetite)	Medium
	α-Fe_2O_3 (Hematite)	Very weak
	SiO_2 (α-Quartz)	Very weak

the constituent compounds in each particulate sample. In addition, most cameras were flushed with helium so that the air scatter which raises the general background in X-ray diffraction patterns was minimized. This also helped to make more weak lines visible. After applying the techniques mentioned about it was possible to produce patterns with 80 to 100 separate, distinctive lines.

A second method used for compound identification consisted of analyzing the various magnetic and density separations produced using the steps outlined in the text and in the flow-chart (Figure 1) described in the following section of this report.

One of the most striking conclusions which may be drawn from these data is that almost all compounds are naturally occurring substances or others whose occurrence may be easily explained such as magnetite from coal flyash. Although the strongest pattern in almost all cases is quartz, it may not be the most abundant since its diffracting power is extremely high when compared with the other compounds found.

Several other conclusions can be drawn from Table 17. First, the density separations are by no means complete, but the differences from expected performance are plausible. As an example, the magnetite appears in some of the lighter fractions. This is very possible if it is associated with burnt organic material in the same particle, such as would occur in incinerator or power plant flyash. Second, the separations do help to enhance compounds which could not be seen in the unseparated sample. There is not much evidence of unusual or out-of-the-ordinary compounds. This may be due to the low concentrations of some of the transition metals which are of interest; possibly the crystallite size or

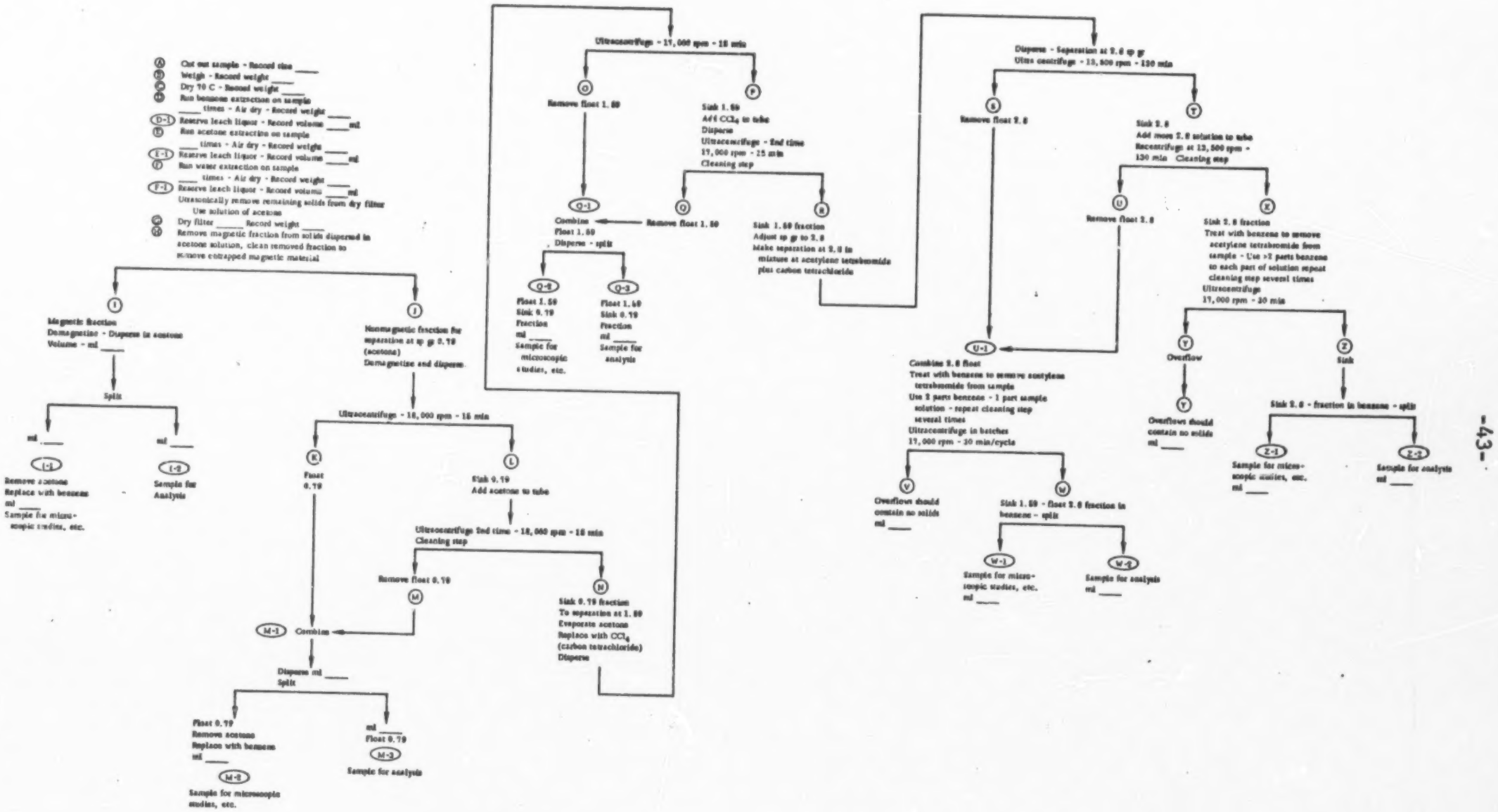
A Cut out sample - Record size
B Weigh - Record weight
C Dry 70 C - Record weight
D Run benzene extraction on sample
times - Air dry - Record weight
D-1 Reserve leach liquor - Record volume ml
E Run acetone extraction on sample
times - Air dry - Record weight
E-1 Reserve leach liquor - Record volume ml
F Run water extraction on sample
times - Air dry - Record weight
F-1 Reserve leach liquor - Record volume ml
Ultrasonically remove remaining solids from dry filter
Use solution of acetone
G Dry filter Record weight
G-1 Remove magnetic fraction from solids dispersed in acetone solution, clean removed fraction to remove entrapped magnetic material
I Magnetic fraction
Demagnetize - Disperse in acetone
Volume - ml
Split
I-1 Remove acetone
Replace with benzene
ml
Sample for microscopic studies, etc.
I-2 Sample for Analysis
J Nonmagnetic fraction for separation at sp gr 2.79 (acetone)
Demagnetize and disperse
Ultracentrifuge - 18,000 rpm - 15 min
K Float 2.79
L Sink 2.79
Add acetone to tube
Ultracentrifuge 2nd time - 18,000 rpm - 15 min
Cleaning step
M Remove float 2.79
M-1 Combine
Disperse ml
Split
Float 2.79
Remove acetone
Replace with benzene
ml
M-2 Sample for microscopic studies, etc.
ml
Float 2.79
M-3 Sample for analysis
N Sink 2.79 fraction
To separation at 1.80
Evaporate acetone
Replace with CCl_4 (carbon tetrachloride)
Disperse
Ultracentrifuge - 17,000 rpm - 15 min
O Remove float 1.80
O-1 Combine
Float 1.80
Disperse - split
O-2 Float 1.80
Sink 2.79
Fraction
ml
Sample for microscopic studies, etc.
O-3 Float 1.80
Sink 2.79
Fraction
ml
Sample for analysis
P Sink 1.80
Add CCl_4 to tube
Disperse
Ultracentrifuge - 2nd time
17,000 rpm - 15 min
Cleaning step
Q Remove float 1.80
R Sink 1.80 fraction
Adjust sp gr to 2.8
Make separation at 2.8 in mixture of acetylene tetrabromide plus carbon tetrachloride
Disperse - Separation at 2.8 sp gr
Ultracentrifuge - 13,500 rpm - 130 min
S Remove float 2.8
T Sink 2.8
Add more 2.8 solution to tube
Recentrifuge at 13,500 rpm - 130 min Cleaning step
U Remove float 2.8
U-1 Combine 2.8 float
Treat with benzene to remove acetylene tetrabromide from sample
Use 2 parts benzene - 1 part sample solution - repeat cleaning step several times
Ultracentrifuge in batches
17,000 rpm - 30 min/cycle
V Overflows should contain no solids
ml
W Sink 1.80 - float 2.8 fraction in benzene - split
W-1 Sample for microscopic studies, etc.
ml
W-2 Sample for analysis
ml
X Sink 2.8 fraction
Treat with benzene to remove acetylene tetrabromide from sample - Use >2 parts benzene to each part of solution repeat cleaning step several times
Ultracentrifuge
17,000 rpm - 30 min
Y Overflow
Y Overflows should contain no solids
ml
Z Sink
Sink 2.8 - fraction in benzene - split
Z-1 Sample for microscopic studies, etc.
ml
Z-2 Sample for analysis
ml

FIGURE 1. FLOW SHEET DIAGRAM FOR SEPARATION OF PARTICLES PRIOR TO ANALYSES

diffracting power effects tend to make the minor compounds invisible in a sample which consists of many particles.

Electron Microprobe Examination

The electron microprobe does not identify compounds per se; rather, it identifies areas of a sample where two or more elements occur in the same spatial pattern. By inference, when certain groupings of elements recur in several areas, it can be assumed that a specific compound, alloy, or intimate mixture is present. This information is valuable as a confirmation of the identifications when interpreting the data using other techniques.

The particulates from ambient urban air collected on Millipore filters from each of 5 cities - Cincinnati (000451), Denver (000475), St. Louis (000501), Washington (000513), and Chicago (000463) - were examined using the electron microprobe. The purpose of this examination was to show the distribution of the elements in the samples and the elemental associations in individual particles as mentioned above.

For the microprobe examination, a 1-cm^2 sample was taken from the filter from each city. Many areas on each sample were examined to locate an area that would show as many of the selected elements as possible. A back-scattered electron image of each area was obtained and X-ray images of the elements seen in the area were taken to show their distribution and association.

Examination of the samples showed Fe, Pb, Cu, Zn, Mn, and S were generally distributed throughout most of the sample. The X-ray distribution pictures showed that the Pb, Cu, Zn, and S are associated, and generally follow the same patterns in the pictures. Random segregated spots of these elements were also found in several areas of the samples. Iron in the samples was quite abundant and appeared as many segregated spots of varying intensity. Many of

the Fe spots had Mn associated with them and an occasional Fe particle showed evidence of Ni or Cr. The Zr, V, and Mo particles seen in these samples appeared to be isolated random particles with no association with other elements. These elements are probably present as oxides, but this assumption was not checked on the microprobe because oxygen by EMP is quite insensitive*. No Br was seen in any of the samples above the background. Some traces of Cl were seen in some areas of the samples but the intensity was too low to obtain X-ray pictures. The Cl had no direct association with any of the other elements. Other elements checked in the samples were Ca, Si, Ti, and C. Large amounts of Ca and Si were seen and in most cases found to be associated with each other. Titanium, a rather ubiquitous element, also was associated generally with Ca or Si. Carbon was high, with some segregated spots and was general throughout the samples. From other work it is thought probable that about half of the C is hydrocarbon, i.e., soluble in organic solvents.

In Cincinnati sample many of the elements of interest, except Br and Cl, were found and X-ray images were taken to show distributions and associations. For this sample, the distribution pictures showed that the Pb, Cu, Zn, and S followed the same pattern and are apparently associated. The Mn was associated with some of the more intense spots of Fe. The Ni seen in this sample also had Fe associated with it. A few low intensity spots of Cr were detected but showed no direct association with any of the other elements. The V and Zr particles observed seem to be isolated random particles with no direct association with other elements.

The St. Louis sample showed the same distributions and associations as described for the Cincinnati sample. No V could be found in this sample and the Br and Cl could not be found above background.

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*Since this work was done, a new crystal was installed that can analyze for both C and O with improved sensitivity.

In the Denver sample the Pb and Cu followed the same pattern in the distribution pictures. In this sample the Zn and S showed very low levels and did not follow Pb and Cu patterns as they had in the two previous samples. The Mn and Ni in this sample appeared to be associated with Fe particles.

A second area was located in this sample where two Mo particles were detected, one particle showing no particular association with any of the other elements, while the other particle showed association with high Cu, low Cr, and low Pb. It was found that the distributions for Pb, Cu, Zn, etc., were generally the same as in the first area. No V was detected in either area and Br and Cl were not seen above background.

In the Chicago sample the Pb, Cu, and Zn appeared to be associated and followed the same pattern. The S in this area did not follow the same pattern as the Pb, Cu, and Zn and did not show any direct association with the other elements. The high intensity Ni spots in this area had low Fe associated with them. The Mn in this area was generally quite low but a single large particle of rather intense Mn was found with no apparent association with the other elements. A second area showed an intense particle of Cr but this particle showed no association with other elements. No V or Zr were found in this sample and no Br or Cl were detected above background.

The Washington sample was collected on a nylon-reinforced cellulose ester Millipore filter. In this sample the Pb, Cu, and S distributions appeared to follow the same patterns. There was no Zn detected in this area above background and there was virtually no Mn except for low intensity spots associated with Fe. The Ni and Cr seen in this area were associated. Iron was also detected in the same spot. Random isolated spots of V and Zr were detected in the sample but showed no association with other elements. No Br or Cl was detected above background in this sample.

In the course of the examination of these samples it was found that the elemental associations of individual particles were difficult to obtain due to the interference from the massive deposit of submicron particles, including (probably) organics and soot, that surrounded the particles. To overcome this difficulty it seemed logical to separate and redisperse the particles. A 1-cm^2 portion of filter 000451 from Cincinnati was suspended in acetone and the deposit removed from the filter ultrasonically. The suspended material was then centrifuged and the supernatant acetone was removed. The residue (insoluble phase) was resuspended in 10 ml of benzene and treated ultrasonically to remove any benzene soluble organics remaining in the material. A 1 ml aliquot of the suspended material was filtered on a silver filter for microprobe examination. The microprobe examination revealed many different types of particles.

Listed in Table 18 are several types of particles from the various filters showing their elemental associations.

SEPARATION TECHNIQUES

There are at least 4 physical methods for separating particles. These are hand-picking similar particles as viewed by optical microscopy; Continuous Particle Electrophoresis; particle size separation; and density separation. Separations of one type or another are almost imperative because it is difficult, if not impossible, to determine the contribution of each of the various particle types to the analytical results from total collections of airborne particulates.

Density Separation

The density separations are best performed on filters that do not shed fibers, that do not disintegrate during ultrasonic agitation in solvents, and

TABLE 18. ELEMENTAL ASSOCIATIONS OBSERVED IN AIR PARTICULATE SAMPLES[a]

Primary[b]	Associated[c]
Ca	Si, Ti
Cr	Fe, Cu, Mn, S
Cu	Zn, Fe, S
Fe	--
Fe	Cu, S
Fe	Mn, S, Si, Ca, C
Fe	Ni, Cr, Mn, S, Cu, Zn
Pb	Cl, S
Si	--
Si	Ca, Ti

(a) Composite of several filters.
(b) The vertical listing is alphabetical by major element and implies no order of concentration.
(c) The associated elements in each horizontal line are listed in approximate decreasing concentration.

that do not have a gross amount of the sample trapped far below the filter surface in tortuous channels. The all-nylon Millipore Type NRWP proved satisfactory; although not tried for separation treatments, the Selas Flotronics silver filters also should be satisfactory.

A combined density - particle size separation is the method generally employed in the mineral dressing field and is probably the best of three particle size and/or density methods, however, the time required to carry out the work would be prohibitive if large numbers of samples are involved. For this reason the above method was not employed. However, should it become necessary or desirable to make better separations, this approach could be employed for a limited number of samples.

After it was decided to perform the separations by density, a flow-sheet detailing the processing of each sample was prepared as shown in Figure 1. Specific gravity separations are made at gravities of 0.79, 1.59, and 2.80. These were selected for ease of operation because the liquids are commercial products.

Because of the complexity of the flow-sheet, no detailed description of the processing of the samples is presented here. However, a listing of the products, or fractions resulting from the processing of each sample, is shown below.

(1) A benzene leach solution containing components of the sample soluble in benzene.

(2) An acetone leach solution containing components of the sample not soluble in benzene but soluble in acetone.

(3) An aqueous solution containing water soluble components of the sample.

(4) A cleaned magnetic fraction.

(5) A very light density fraction containing the components of the sample with a specific gravity $\leq$0.79.

(6) A fraction containing the components of the sample with specific gravities between 0.79 and 1.59.

(7) A fraction containing the components of the sample with specific gravities between 1.59 and 2.80. This fraction is expected to contain the silicates.

(8) A fraction containing the components of the sample with specific gravities greater than 2.80.

The first two samples separated by heavy liquids were St. Louis (00500) and Denver (000475). The recovery of material in the float-sink products in each case was higher in weight than the unseparated sample. In one case the gain was 66 percent (St. Louis) and in the Denver sample, 20 percent. Usually a loss is experienced - in materials in the size range of 5 to 100 μm the losses are about 4 to 6 percent. The high recoveries (66 and 20 percent) indicated that somewhere in the procedure contamination was occurring. The techniques were reviewed and the following changes were put into effect.

(1) All solutions - i.e., acetone, benzene, water, wash solutions, carbon tetrachloride, and acetylene tetrabromide were filtered on Millipore filters before using. In the first two separations (000500 and 000475) the C.P. reagents were not filtered. Subsequently, filtration showed that the C.P. reagents such as acetylene tetrabomide did contain solids.

(2) Additional washes in the heavy liquid.

In the next separation (Cincinnati 000452) a gain of 0.9 percent was recorded, a very satisfactory result. The next sample processed (St. Louis

000501) showed a loss of 19.3 percent. It is possible that these losses, about a factor of two higher than normally expected, were due to cohesion between the particles and the glassware and stainless steel tubes, but it is not known why similar losses did not occur with other samples. The data for these separations are given in Table 19.

Conclusions and Observations

The results with the 000452 Cincinnati sample show that the technique is applicable but does require extreme care. As was seen in the section on XRD analysis, the density separations are not "clean"; i.e., compounds such as α-Quartz appear in most fractions. Nevertheless, some degree of enrichment was accomplished, especially in the magnetic separation. In this light, the density and magnetic separations are very useful, even though they are tedious and time-consuming.

Certain characteristics peculiar to a particular sample were noted during the specific gravity separations; e.g., the Cincinnati sample could not be subjected to the specific gravity separations until it had been water leached. For this reason, the water leach was included in the processing of all Subsequent samples. The Cincinnati sample could not be processed after the benzene and acetone leaches because a substantial amount of the material on the filter could not be removed ultrasonically from the filter and dispersed into the acetone solution solution prior to the magnetic separation. An examination by means of optical microscopy of the material on the filter before water leaching revealed that the material on the filter appeared to be caked and cemented onto the membrane substrate. This condition was not observed on the St. Louis or Denver samples. The caking was interpreted

TABLE 19. SEPARATION RECOVERY DATA

Step	Wt, mg	Percent of Total
000502 - Cincinnati		
Loss - dry 70 C	0.7	0.6
Loss - C_6H_6 leach	5.0	4.2
Loss - $(CH_3)_2CO$ leach	13.2	11.1
Loss - H_2O leach	34.1	28.7
To separations	65.9[a]	55.4
Totals	118.9	100.0
Separations		
Magnetic	2.0	1.7[b]
Density <0.79	0.0	0.0
Density >0.79-<1.59	3.1	2.6[b]
Density >1.59-<2.8	24.4	20.3[b]
Density >2.8	37.0	30.8[b]
Subtotals	66.5[a]	55.4[b]
000475 - Denver		
Loss - dry 70 C	1.8	1.4
Loss - C_6H_6 leach	9.0	7.0
Loss - $(CH_3)_2CO$ leach	7.3	5.7
Loss - H_2O leach	4.2	3.3
To separations	106.2[c]	82.6
Totals	128.5	100.0
Separations		
Magnetic	0.3	0.2[d]
Density <0.79	6.7	4.3[d]
Density >0.79-<1.59	2.7	1.7[d]
Density >1.59-<2.8	45.6	29.5[d]
Density >2.8	72.3	46.8[d]
Subtotal	127.6[c]	82.6[d]
000500 - St. Louis		
Loss - dry 70 C	1.2	4.2
Loss - C_6H_6 leach	0.4	1.4
Loss - $(CH_3)_2CO$ leach	5.1	17.9
Loss - H_2O leach	7.0	24.6
To separations	14.8[e]	51.9
Totals	28.5	100.0
Separations		
Magnetic	0.1	0.2[f]
Density <0.79	2.9	6.1[f]
Density >0.79-1.59	2.1	4.4[f]
Density >1.59-<2.8	13.8	29.3[f]
Density >2.8	5.6	11.9[f]
Subtotals	24.5[e]	51.9[f]

TABLE 19. (Continued)

Step	Wt, mg	Percent of Total
000501 - St. Louis		
Loss - dry 70 C	1.4	0.9
Loss - C_6H_6 leach	8.5	5.7
Loss - $(CH_3)_2CO$ leach	6.8	4.6
Loss - H_2O leach	37.1	24.9
To separations	95.3(g)	63.9
Totals	149.1	100.0
Separations		
Magnetic	0.0	0.0
Density <0.79	0.0	0.0
Density >0.79-<1.59	3.4	2.8(h)
Density >1.59-<2.8	37.8	31.4(h)
Density >2.8	35.8	29.7(h)
Subtotals	77.0(g)	63.9(h)

(a) These values should agree; recovery therefore equals $\frac{66.5}{65.9}$ x 100 = 101 percent.

(b) Normalized to 100.0 percent overall recovery; i.e., separated fractions are based on 65.9 mg, not 66.5 mg.

(c) These values should agree; recovery therefore equals $\frac{127.6}{106.2}$ x 100 = 120 percent.

(d) Normalized to 100.0 percent overall recovery; i.e., separated fractions are based on 106.2 mg, not 127.6 mg.

(e) These values should agree; recovery therefore equals $\frac{24.5}{14.8}$ x 100 = 166 percent.

(f) Normalized to 100.0 percent overall recovery; i.e., separated fractions are based on 14.8 mg, not 24.5 mg.

(g) These values should agree; recovery therefore equals $\frac{77.0}{95.3}$ x 100 = 80.7 percent.

(h) Normalized to 100.0 percent overall recovery; i.e., separated fractions are based on 95.3 mg, not 77.0 mg.

as possibly caused by drying of water soluble material, and therefore a water leach to remove these fractions was effective. This measure corrected the difficulty and thus the water leach step was incorporated into the flow-sheet and employed in the fractionation of the other samples to preserve a consistent treatment of all the samples. It is recognized that water leaching implies ionic salts, and that chemical associations present in the as-collected sample probably will be altered when the water leach is dried. This is an overall problem in specie identification. Certainly particles as emitted from point or diffuse sources must be altered during their stay in the atmosphere, during their collection, and probably during their analysis. In other words, it is highly probable that at least some ionic interchange will occur in the atmosphere, more exchange on the filter owing to close contact, and still more in the water leaching step. For example, assume one point source emits NaCl, and another emits $ZnSO_4$. Under humid conditions, especially fog or rain, an equilibrium of NaCl, Na_2SO_4, $ZnSO_4$, and $ZnCl_2$ could occur. Upon water leaching, the effect would be greater, and depending upon the dissociation constants involved, could produce a completely random distribution of all possible salts. These effects, of course, would decrease as the solubility of the emitted compounds decreased.

Particle Size Separation

A particle size separation of a sample was made in acetone assuming an average sp gr of 2.7. Six fractions of various sizes (see Table 20) were cut out by sedimentation in the ultracentrifuge.

The material balance showed a recovery of +14 percent; considering that the acetone was not filtered (the need for filtering was not yet discovered since this work was done before the density separation work), the results indicate that it should be possible to obtain products separated into various sizes.

TABLE 20. PARTICLE SIZE DISTRIBUTION[a]

	mg	Percent of Total Sample
Loss - dry 110 C	0.4	3.6
Loss - C_6H_6 leach	0.6	5.5
Loss - $(CH_3)_2CO$ leach	0.3	2.7
To separations	9.7[b]	88.2
	11.0	100.0
Separations(μm)		
<0.1	2.94	23.4[c]
>0.1-<0.5	1.71	13.6[c]
>0.5-<1.0	1.31	10.4[c]
>1.0-<4.0	3.54	28.2[c]
>4.0-<8.0	0.87	7.0[c]
>8.0	0.69	5.6[c]
	11.06[b]	88.2[c]

(a) Unidentified sample on silver filter.
(b) These values should agree; recovery equals $\frac{11.06}{9.7}$ = 114 percent.
(c) Normalized to 100.0 percent overall recovery; i.e., separated fractions are based on 9.7 mg, not 11.06 mg.

Complete separations, as mentioned earlier, would yield composition versus particle size as well as composition versus density. As the number of fractions is increased, the work involved quickly escalates both for the actual separations and for the analysis of the fractions.

MISCELLANEOUS ANALYSES

S&S Glass Filters

Two S&S glass filters were submitted by Dr. Thompson to be evaluated as possible EPA filter materials. The two grades, 23 and 25, and a comparison Gelman Type E filter, were analyzed semiquantitatively by OES. The results, given in Table 21, show no significant differences, with the exception that S&S Grade 25 may be slightly cleaner with respect to some of the trace metals.

Contact Paper

A sample of contact paper, brought to Battelle by Dr. Thompson as a possible candidate for sample collection, was ashed and analyzed by OES. The ash content, 20.7 percent, compares unfavorably with 0.2 percent for the nylon reinforced Millipore filters, for example. Unless the ash content can be lowered drastically, this paper does not appear suitable for any but very specialized air or particulate sampling applications. The OES and SSMS analyses of the ash are given in Table 22.

Analysis of Effluent From a Reactive Metals Furnace

A small thimble (No. 104) composed of fibrous materials used to sample the stack effluent of a reactive metals furnace was analyzed for elemental and

TABLE 21. ANALYSIS OF S&S GLASS FILTERS
(Weight Percent in Filter)
(Optical Emission Spectrography)

	Sample Designation		
Element	S&S Grade 23	S&S Grade 25	Gelman Type E
B	2.	1.	2.
Na	5.	5.	5.
Mg	0.2	1.	0.2
Al	2.	2.	2.
Si	Major	Major	Major
Ca	3.	6.	3.
Ti	<0.01(T)	<0.01(T)	0.01
Cr	0.02	<0.01	<0.01
Mn	0.005	<0.005(T)	0.005
Fe	0.04	0.05	0.04
Cu	0.005	0.005	0.005
Zn	4.	<0.1	4.
Sr	0.05	0.01	0.04
Ba	4.	0.1	4.

T = Trace.

TABLE 22. ANALYSIS OF CONTACT PAPER
(ppmw in Paper)[a]

Element	SSMS[b]	OES[b]	Element	SSMS[b]	OES[b]
Li	6.		As	0.4	
Be	0.04		Se	-	
B	2.		Br	-	
C	-		Rb	0.6	
N	-		Sr	6.	
O	-		Y	0.6	
F	4.		Zr	6.	
Na	400.		Nb	2.	
Mg	400.	400.	Mo	-	
Al	30,000.	30,000.	Ag	≤0.2	
Si	20,000.	40,000.	Cd	-	
P	30.		In	-	
S	6.		Sn	4.	
Cl	20.		Sb	<1.	
K	600.	600.	Te	-	
Ca	600.	200.	I	-	
Sc	3.		Cs	-	
Ti	30,000.	30,000.	Ba	6.	
V	6.	20.	La	2.	
Cr	20.		Ce	4.	
Mn	<2.		Pr	2.	
Fe	200.	200.	Nd	6.	
Co	<0.4		Sm	2.	
Ni	3.	<10.	Ta	<0.6	
Cu	1.	10.	Pb	2.	
Zn	10.		Bi	≤0.1	
Ga	<4.		Th	2.	
Ge	<3.		U	0.4	

(a) Ash = 20.7 weight percent (compare with WSWP Millipore nylon reinforced cellulose ester filters, whose ash content ≃0.2 percent).
(b) SSMS = Spark-source mass spectrography.
(b) OES = Optical emission mass spectrography.

compound constituents. Semiquantitative optical emission spectrography and spark source mass spectrography analyses were performed on the sample. The results are presented in Table 23.

Another aspect of this analysis was the ion or compound identification. X-ray diffraction was used in an attempt to identify the larger particulates since the X-ray diffraction effect breaks down as particle size becomes smaller than about 1000 angstroms. A preliminary powder film showed SiO_2 (α-Quartz) to be the only phase identifiable by X-ray diffraction. A second pattern produced by grinding several milligrams of sample and using techniques to provide maximum sensitivity showed Fe_3O_4 to be the major component and SiO_2 (α-Quartz) to be the minor component with a few very weak lines not identified.

TALKS AND PAPERS

The following talks relating to air pollution in general or to the analysis of particulates in air have been given. The information is included to indicate the growing interest of the general public and specialized groups about this subject. At each presentation, a special acknowledgement was made of NAPCA or EPA support with a "soft sell" suggestion for public support of increased Federally sponsored research and enforcement.

(1) Sunday, October 25, 1970: Presentation before about 80 members of an adult study group at the Broad Street Presbyterian Church, Columbus.

(2) Tuesday, November 3, 1970: Presentation and laboratory tour in cooperation with others of the BCL staff, for a group of 40 graduate students in Ecology at The Ohio State University.

TABLE 23. MASS AND OPTICAL EMISSION SPECTROGRAPHIC ANALYSIS OF REACTIVE METAL FURNACE EFFLUENT SAMPLE (ppmw)

Element	OES(a)	SSMS(a)	Element	OES(a)	SSMS(a)
Li		40.	Ge		<40.
Be		0.2	As		60.
B		60.	Se		≤10.
F		40.	Br		40.
Na		High	Rb		60.
Mg	2000.	High	Sr		200.
Al	2.%	High	Y		10.
Si	5-10.%	High	Zr		20.
P		200.	Nb		2.
S		6000.	Mo	300.	100.
Cl		800.	Cd		≤10. (c)
K		High	Sn		150.
Ca	2.%	High	Sb		40.
Sc		10.	Te		≤10.
Ti	300.	600.	I		4.
V		60.	Cs		4.
Cr	1000.	1000.	Ba		200.
Mn	1.%	High	La		10.
Fe(b)	20-40.%	High	Ce		20.
Co		100.	Pr		1.
Ni	2000.	400.	Ta		<4.
Cu	2000.	1000.	W		≤40. (c)
Zn		400.	Pb	1000.	1000.
Ga		4.	Bi		≤10. (c)

(a) OES = Optical emission spectrography
SSMS = Spark source mass spectrography.
(b) Matrix element.
(c) Uncertainty due to memory from previous samples.
_ Preferred value underlined.

(3) Tuesday, November 24, 1970: Presentation before about 40 members of a social club comprised of persons from three Mennonite churches in Mahoning and Columbiana counties.

(4) Tuesday, January 26, 1971: A 1-1/2-hour lecture and discussion period before the Pittsburgh local section of a group of students, teachers, industry personnel, and others interested in Spectroscopy. The sampling and analysis of air particulates was the main theme.

(5) Thursday, March 4, 1971: An invited paper on the spark source analysis of air particulates, at the Pittsburgh Conference, held in Cleveland.

(6) Wednesday, March 10, 1971: Presentation before about 20 members of an adult study group at Overbrook Presbyterian Church, Columbus.

(7) Friday, May 7, 1971: Arranged for and presided at a half-day session in Atlanta, Georgia, at the annual American Society for Mass Spectrometry meeting, on the analysis of air particulates using spark source mass spectrographic and ion bombardment microanalyzer techniques. A paper by Mr. Blosser and Dr. Thompson was presented at this session.

A paper on the complete elemental composition of air particulates, based on this and last year's work has been prepared for submission to Science with Dr. Thompson as coauthor.

FUTURE WORK

No further work is planned on this project. A proposal with two options has been submitted to EPA to continue and expand the efforts described in this report.

MAN-HOURS AND FUNDS EXPENDED

From the period June 30, 1970, through July 24, 1971, the overall costs are expected to be within the funds allotted, and the man-hours expended will be approximately 2500.

APPENDIX

COMPOSITE OF ELEMENTAL COMPOSITIONAL DATA

APPENDIX

COMPOSITE OF ELEMENTAL COMPOSITIONAL DATA

The two tables from the article prepared for submission to "Science" are included in the Appendix. These talbes are a composite of the elemental compositional data generated in this and the preceding contract periods, and therefore represent a good overview of ambient air particulate composition.

TABLE A-1. APPROXIMATE ELEMENTAL CONCENTRATIONS FOUND IN PARTICULATES COLLECTED FROM AMBIENT URBAN AIR
(Nanograms/cubic meter)

Element	Cincinnati	Denver	St. Louis	Washington	Chicago	Philadelphia
H	3,000.	5,000.	5,000.	3,000.	10,000.	4,000.
Li	5.	10.	10.	5.	2.	2.
Be	0.2	0.04	0.4	0.1	<0.1	0.05
B	10.	20.	10.	10.	10.	5.
C	30,000.	40,000.	40,000.	30,000.	100,000.	30,000.
N	3,000.	2,000.	3,000.	2,000.	8,000.	5,000.
F	40.	600.	200.	50.	30.	20.
Na	1,000.	3,000.	3,000.	1,000.	2,000.	1,000.
Mg	2,000.	1,000.	2,000.	2,000.	5,000.	5,000.
Al	3,000.	7,000.	3,000.	3,000.	4,000.	3,000.
Si	6,000.	20,000.	6,000.	10,000.	10,000.	10,000.
P	50.	100.	200.	100.	60.	50.
S	4,000.	2,000.	5,000.	6,000.	7,000.	3,000.
Cl	300.	500.	500.	400.	5,000.	100.
K	1,000.	5,000.	1,000.	2,000.	2,000.	300.
Ca	6,000.	4,000.	20,000.	3,000.	10,000.	8,000.
Sc	1.	2.	1.	1.	1.	10.
Ti	200.	400.	300.	400.	400.	400.
V	10.	20.	20.	100.	50.	200.
Cr	30.	10.	20.	20.	30.	40.
Mn	300.	70.	50.	50.	100.	200.
Fe	5,000.	5,000.	5,000.	4,000.	5,000.	4,000.
Co	3.	5.	3.	5.	10.	20.
Ni	20.	20.	20.	50.	40.	100.
Cu	500.	500.	2,000.	800.	400.	200.
Zn	2,000.	200.	2,000.	400.	500.	500.
Ga	0.5	1.	2.	2.	1.	6.
Ge	0.5	2.	5.	1.	2.	<0.4
As	2.	5.	10.	2.	2.	5.
Se	2.	1.	5.	<1.	2.	2.
Br	50.	50.	50.	50.	50.	40.
Rb	10.	10.	20.	10.	5.	20.
Sr	10.	10.	30.	10.	10.	40.
Y	2.	4.	2.	2.	1.	2.
Zr	10.	20.	10.	10.	10.	10.
Nb	0.4	2.	1.	1.	0.5	0.3
Mo	2.	10.	3.	4.	3.	2.
Ru	<0.04	<0.06	<0.04	<0.01	<0.5	<0.03
Rh	<0.04	<0.2	<0.1	<0.03	<0.06	≤0.01
Pd	≤0.2	<1.	<0.4	<0.1	<0.3	<0.3
Ag	0.2	1.	10.	1.	2.	0.6
Cd	2.	1.	5.	0.3	3.	1.
In	<0.1	<3.	<1.	<0.5	<0.2	<1.
Sn	50.	10.	50.	30.	40.	20.
Sb	2.	5.	5.	3.	5.	60.
Te	≤0.2	<0.2	1.	0.3	≤0.2	≤0.1
I	<0.05	0.5	1.	4.	<0.1	0.1
Cs	0.2	1.	1.	3.	0.7	0.4
Ba	40.	100.	100.	100.	80.	40.
La	3.	10.	2.	4.	10.	20.
Ce	5.	20.	5.	5.	20.	20.
Pr	1.	4.	1.	2.	4.	4.
Nd	3.	10.	3.	2.	10.	7.
Sm	0.4	1.	0.6	0.5	3.	1.
Eu	0.1	0.5	0.4	0.1	0.3	0.2
Gd	0.5	1.	0.5	0.5	2.	0.6
Tb	0.05	0.1	<0.2	0.1	≤0.1	0.2
Dy	<0.3	0.3	0.5	0.2	0.3	0.6
Ho	<0.1	0.1	<0.2	0.1	0.1	0.1
Er	0.05	0.5	<0.2	<0.3	≤0.2	0.3
Tm	0.02	0.01	<0.05	<0.03	0.03	0.06
Yb	0.1	0.2	0.1	<0.3	0.1	0.3
Lu	0.02	0.03	<0.1	<0.02	0.03	≤0.04
Hf	0.1	0.2	0.1	0.1	<0.3	0.2
Ta	<0.1	<0.3	<0.3	≤0.05	0.1	≤0.2
W	0.2	1.	0.5	0.1	0.5	1.
Re	<0.01	0.5	<0.06	<0.01	<0.01	<0.02
Os	<0.01	<0.02	<0.06	<0.02	<0.01	<0.03
Ir	<0.005	<0.02	<0.03	<0.01	<0.01	<0.06
Pt	<0.01	<0.04	<0.1	<0.02	<0.02	<0.03
Au	<0.01	<0.1	<0.03	<0.02	<0.02	<0.06
Hg	≤0.5	2.	<0.3	<0.4	1.	2.
Tl	<0.03	0.1	0.05	≤0.02	≤0.02	0.04
Pb	3,000.	3,000.	3,000.	4,000.	5,000.	2,000.
Bi	0.5	0.6	2.	1.	1.	0.6
Th	0.2	0.2	1.	0.1	0.4	0.2
U	0.2	0.3	2.	0.05	0.2	0.2

TABLE A-2. RANGE AND TYPICAL VALUES FOR ELEMENTS IN PARTICULATES COLLECTED FROM AMBIENT URBAN AIR[a]

(Nanograms/cubic meter)

Element	Low	High	Typical	Element	Low	High	Typical	Element	Low	High	Typical
H	3,000.	10,000.	5,000.	Ge	<0.4	5.	2.	Eu	0.1	0.5	0.2
He	----------not sought----------			As	2.	10.	3.	Gd	0.5	2.	0.6
Li	2.	10.	4.	Se	<1.	5.	2.	Tb	0.05	0.2	0.1
Be	0.04	0.4	0.1	Br	40.	50.	50.	Dy	0.2	0.6	0.3
B	5.	20.	10.	Kr	---------not sought---------			Ho	<0.1	<0.2	0.1
C	30,000.	100,000.	40,000.	Rb	5.	20.	10.	Er	<0.05	0.2	0.1
N	2,000.	8,000.	3,000.	Sr	10.	40.	10.	Tm	0.01	0.06	0.02
O	----------not determined----------			Y	1.	4.	2.	Yb	0.1	0.3	0.2
F	20.	600.	50.	Zr	10.	20.	10.	Lu	<0.02	0.3	<0.05
Ne	----------not sought----------			Nb	0.3	2.	0.5	Hf	<0.1	<0.3	0.1
Na	1,000.	3,000.	2,000.	Mo	2.	10.	3.	Ta	<0.1	<0.3	<0.2
Mg	1,000.	5,000.	2,000.	Tc	---------not sought---------			W	0.1	1.	0.5
Al	3,000.	7,000.	4,000.	Ru	<0.01	<0.5	<0.03	Re	<0.01	0.05	<0.02
Si	6,000.	20,000.	10,000.	Rh	<0.01	<0.2	<0.03	Os	<0.01	<0.06	<0.04
P	50.	200.	100.	Pd	<0.1	<0.4	<0.3	Ir	<0.005	<0.06	<0.03
S	2,000.	7,000.	5,000.	Ag	0.2	10.	1.	Pt	<0.01	<0.1	<0.03
Cl	100.	5,000.	500.	Cd	0.3	5.	2.	Au	<0.01	<0.1	<0.03
Ar	----------not sought----------			In	<0.1	<3.	<1.	Hg	<0.3	2.	1.
K	300.	5,000.	2,000.	Sn	2.	50.	30.	Tl	≤0.02	0.1	<0.04
Ca	3,000.	20,000.	6,000.	Sb	2.	60.	5.	Pb	2,000.	5,000.	3,000.
Sc	1.	10.	1.	Te	≤0.1	1.	≤0.2	Bi	0.5	2.	1.
Ti	200.	400.	300.	I	≤0.05	4.	0.1	Po	----------not sought----------		
V	10.	200.	30.	Xe	---------not sought---------			At	----------not sought----------		
Cr	10.	40.	20.	Cs	0.2	3.	1.	Rn	----------not sought----------		
Mn	50.	300.	100.	Ba	40.	100.	80.	Fr	----------not sought----------		
Fe	4,000.	5,000.	5,000.	La	2.	20.	5.	Ra	----------not sought----------		
Co	3.	20.	5.	Ce	5.	20.	10.	Ac	----------not sought----------		
Ni	20.	100.	30.	Pr	1.	4.	2.	Th	0.1	1.	0.2
Cu	200.	2,000.	500.	Nd	2.	10.	5.	Pa	----------not sought----------		
Zn	200.	2,000.	500.	Pm	---------not sought---------			U	0.05	2.	0.2
Ga	0.5	5.	2.	Sm	0.4	3.	1.	Transuranic elements not sought.			

(a) Cincinnati, Denver, St. Louis, Washington, D. C., Chicago, Philadelphia. High and low values are weighted averages of 2 to 204 filters for each city. They are not the extreme values from filter to filter or run to run.